

This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Y. 5 7cc 10



Library
of the
University of Wisconsin

THE ART OF ILLUMINATION

Published by the

McGraw-Hill Book Company

New York

Successors to the Book Departments of the

McGraw Publishing Company Hill Publishing Company

Publishers of Books for

Electrical World
Engineering Record
Electric Railway Journal
Metallurgical and Chemical Engineering
The Engineering and Mining Journal
American Machinist
Coal Age
Power



The Court of Honor—Hudson-Fulton Celebration. *Frontispiece*

THE ART
OF
ILLUMINATION

BY

LOUIS BELL, PH. D.

Fellow, American Academy of Arts and Sciences; M. A. I. E. E.; Past-President, The Illuminating Engineering Society; Vice-President, The Illuminating Engineering Society (London)

SECOND EDITION
THOROUGHLY REVISED, ENLARGED AND RESET

McGRAW-HILL BOOK COMPANY
239 WEST 39TH STREET, NEW YORK
6 BOUVERIE STREET, LONDON, E.C.
1912

COPYRIGHT, 1912,
BY THE
McGRAW-HILL BOOK COMPANY

Printed by
The Maple Press
York, Pa.

166353
AUG 2 1912
SJ
B41
2

PREFACE.

SINCE the first edition of this book was published profound and revolutionary changes have taken place in the available materials of artificial illumination. Among electrical illuminants entirely new types of arc light have come into general use, and the carbon incandescent lamp is being rapidly pushed into obsolescence by the metallic filament lamps which now dominate electric lighting practice.

In the field of gas lighting, the inverted mantle burners of both large and small capacity, and the high pressure mantle burners, have pushed their way to the front and radically changed the conditions of economy which previously existed. Auxiliaries of every kind, and particularly shades and reflectors of greatly improved types, have been so multiplied as to meet almost every possible requirement. All these considerations have made necessary a very complete revision of the parts of this volume dealing with practical lighting. Moreover, the art of illuminating engineering has been enriched by a large amount of valuable experience within the past few years, and its principles are now founded on a more secure scientific basis. The general principles of the art, however, remain the same and its importance in practical life is at last being adequately appreciated.

MARCH, 1912.

CONTENTS.

CHAP.		PAGE
	PREFACE	vii
I.	LIGHT AND THE EYE	1
II.	PRINCIPLES OF COLOR	25
III.	REFLECTION AND DIFFUSION	37
IV.	STANDARDS OF LIGHT AND PHOTOMETRY	52
V.	THE MATERIALS OF ILLUMINATION — ILLUMINANTS OF COMBUSTION	77
VI.	THE MATERIALS OF ILLUMINATION — INCANDESCENT BURNERS	99
VII.	THE ELECTRIC INCANDESCENT LAMP	116
VIII.	THE ELECTRIC ARC LAMP	150
IX.	SHADES AND REFLECTORS	184
X.	DOMESTIC ILLUMINATION	207
XI.	LIGHTING LARGE INTERIORS	233
XII.	EXTERIOR ILLUMINATION	279
XIII.	DECORATIVE AND SCENIC ILLUMINATION	316
XIV.	THE ILLUMINATION OF THE FUTURE	336
	INDEX	345

THE ART OF ILLUMINATION.

CHAPTER I.

LIGHT AND THE EYE.

WHILE even the Esquimaux and the Patagonians use artificial light and all civilized peoples count it a necessity, it is seldom used skillfully and with proper knowledge of the principles that should govern its employment. Since the introduction of electric lights that very facility of application which gives them unique value has encouraged more zeal than discretion in their use. It is the purpose of the present volume to set forth some of the fundamental doctrines, optical, physiological, and æsthetic, which underlie the proper use of artificial illuminants, and to point out how they may be advantageously adapted to existing conditions.

To begin with, there are two general purposes which characterize two quite distinct branches of the art of illumination. First comes the broad question of supplying artificial light for carrying on such avocations or amusements as are extended into the hours of darkness. Quite apart from this is the case of scenic illumination directed at special objects and designed to produce particular effects or illusions. Lighting a shop or a house exemplifies the one, lighting a picture gallery or the stage of a theater the other. Each has a distinct purpose, and requires special means for its accomplishment. Confusing the purposes or mixing the methods often leads to serious mistakes. Sometimes both general and scenic illumination have to be used coincidently, but the distinction between them should be fully realized even when it cannot fully be preserved.

General illumination, whether intended to serve the ends of work or play, must fulfill the following conditions: it must be amply adequate in amount, suitable in kind, and must be so applied as not to react injuriously upon the eye.

It must be remembered that the human eye is not merely

a rather indifferent optical instrument, but a physical organ which has through unfathomable ages accumulated the characters wrought upon it by evolution, until it bears the impress and incurs the limitations of its environment. It works best over a rather limited retinal area and through a range in intensity of light which, although great, is yet immensely smaller than the range available to nocturnal creatures. It has, moreover, become habituated to, and adapted to, light coming obliquely from above, and resents strong illumination, whether natural or artificial, from any other direction. It seems to be well established, for example, that the distress caused by the reflected glare from sand, or water, or snow, and the grave results which follow prolonged exposure to it, are due not only to the intensity of the light but to the fact that it is directed upward into the eye and is quite insufficiently stopped by the rather transparent lower eyelid. Ordinary glasses are inefficient protection in this case, but if the lower part of the eye be thoroughly guarded little difficulty is found. The Alaskan Indians have evolved a very effective protection against snow blindness in the shape of leather goggles with the eye arranged as shown in Fig. 1. The eyepiece is merely a round bit of dark leather with a semicircular cut made for the peephole, the resulting flap being turned outward and downward, so that the eye is fully guarded from the brilliant upward beams. Blackening the whole lower eyelid with burnt cork is stated by one distinguished oculist to be completely efficacious for the same reason.

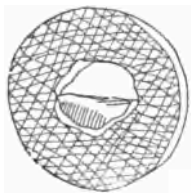


Fig. 1. — Indian Goggles.

It is more than likely that the bad effects ascribed to the habit of reading while lying down are due largely to the unwonted direction of the illumination, as well as to the unusual position of the eye's axis.

All these matters are of fundamental importance in planning any illumination to facilitate hard visual work. Their significance is that we are not at liberty to depart widely from the distribution and character of natural daylight illumination. Of course, one realizes immediately that the eye is neither fitted nor habituated to working to advantage in anything like the full strength of sunlight; but its more general properties—steadiness, dominant wave length, downward oblique direction, wide and strong dif-

fusion, freedom from sharp and black shadows — these must be followed rather closely in ordinary artificial illumination, or the eye, that has been taking form through a million years of sunlight and skylight, will resent the change. The eye is automatically adjustable, it is true, for wonderfully diverse conditions, but persistent and grave changes in environment are more than it can bear.

Now from a practical standpoint the key to artificial illumination is found in the thoughtful contemplation of what is known as Fechner's law, relating to the sensitiveness of the eye to visual impressions. It is stated by Helmholtz substantially as follows: "Within very wide limits of brightness, differences in the strength of light are equally distinct or appear equal in sensation, if they form an equal fraction of the total quantity of light compared." That is, provided the parts of the visual picture remain of the same *relative* brightness, the distinctness of detail does not vary materially with great changes of absolute brightness. Now since, barring binocular vision, our whole perception of visible things depends, in the absence of color contrasts, upon differences of illumination, the importance of the law just stated needs little comment. It implies what experience proves, that within a rather wide range of absolute brightness of illumination our vision is about equally effective for all ordinary purposes.

Fechner's law, to be sure, fails when extremely brilliant lights are concerned. Few persons realize, for instance, that the sun is twice as bright at noon as it is when still 10 to 15 degrees above the horizon, still less that its brilliancy is reduced more than a hundred-fold as its lower limb touches the horizon. Yet while the eye does not detect very small changes or properly evaluate large ones in a body so bright as the sun, the mere fact that one can see to work or read about equally well from sunrise to sunset is most convincing as to the general truth of the law. Full sunlight at noon is over-bright for the eye if it falls directly upon the work, but with half of it or less one can get along very comfortably.

All this is most important from the standpoint of artificial illumination, since it means that within rather wide limits of intensity artificial lighting remains about equally effective for most practical purposes.

The actual amount of illumination necessary and desirable, the

terms by which we measure it, and the laws that govern its intensity are matters of primary importance, which must now occupy our attention.

To arrive at a logical determination of the amount of illumination necessary for general or special purposes, one must turn to the actual properties of the eye with respect to seeing those things which are customarily the objects of artificial illumination. The fundamental fact at the basis of vision is that the eye can perceive within a very wide range of absolute intensity a substantially constant fractional difference of luminosity in the objects seen. This is the purport of Fechner's law, to which reference has already been made, and the fractional difference mentioned is well known as Fechner's fraction. Its numerical value for ordinary eyes and ordinary intensities of illumination is about 0.01; that is, two adjacent surfaces can, under ordinary circumstances, be distinguished as separate, if one reflects to the eye about one per cent more effective light than the other.

It is here assumed that the objects are of approximately the same color, so that shade perception is the chief faculty of vision involved. Even if the colors are somewhat different, the value of Fechner's fraction is not greatly altered, provided the general luminosity of the two surfaces remains as stated. In fact at a little distance even somewhat strongly contrasted colors blend into each other in a way that is altogether surprising, if they approach closely the same general luminosity. Now, while Fechner's fraction is fairly constant over a wide range of intensities, it varies, as already stated, when one attempts to judge extremely brilliant lights; and also one easily realizes that as twilight deepens his power of shade perception is seriously impaired.

It is this variation of Fechner's fraction which determines the minimum amount of artificial, or for that matter, natural light, necessary for clear vision so far as shade perception is concerned. Now, illumination sufficient to bring Fechner's fraction up to its normal value, that is, to get the eye into its steady state with respect to shade perception, is sufficient, so far as this matter is concerned, for good vision, and anything above such amount represents waste light.

Beside Fechner's fraction, which expresses shade perception, another factor of equal importance enters into practical seeing. This second factor is visual acuity, that is, the ability to see fine

detail, assuming strong contrast, as, for example, between type and the background of the page. This power of acuity is in a great measure independent of the power of shade perception as such, being determined by other physiological peculiarities of the eye. It is possible, for example, to find eyes of normal acuity in which shade perception is somewhat deficient, and vice versa. Acuity seems to depend on the structure of the retina and the quality of the eye as an optical instrument rather than upon its direct or secondary sensitiveness to stimulation by light.

In order, therefore, to see things really well one must have not only sufficient light to bring the eye to its steady state, but sufficient also to give the eye its normal powers of acuity. The way in which one's power of perceiving detail decreases in dim light is familiar, and the variation of acuity with the intensity of the illumination affords an independent criterion of the necessary requirements in artificial lighting. Fortunately the properties of the eye with respect to both shade perception and acuity have been the subjects of many investigations, so they may be considered as on the whole well determined.

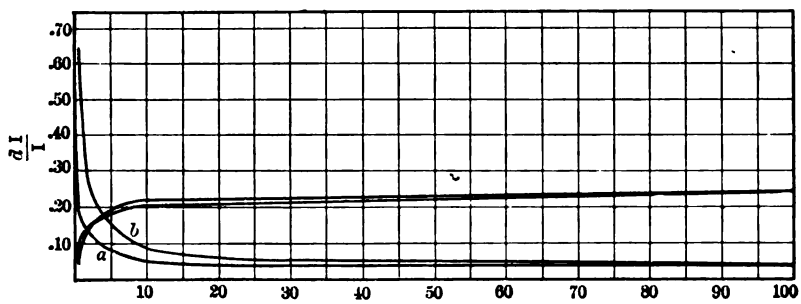


Fig. 2.

Fig. 2 shows graphically the relation of strength of illumination to shade perception and to acuity, as determined by Dr. Uhthoff, and Drs. Koenig and Brodhun respectively. Curves *a* and *b* give Fechner's fraction for the normal eye for intensities up to 100 meter-candles. Curve *a*, the lower one, is for white light, while curve *b* is for deep-crimson light. A little inspection will show that for values of the illumination below 2 or 3 meter-candles shade perception is somewhat deficient both for white light and for crimson light, while between 10 and 20 meter-candles of

illumination both curves rapidly merge and are settling down to their steady value. Above 20 to 30 meter-candles they are practically coincident, and power of discriminating thereafter remains steady up to at least some thousands of meter-candles of intensity.

Hence when the light reaching the eye is above 20 to 30 meter-candles further increase is of comparatively little assistance to vision so far as shade perception is concerned. The other curves, which are for all practical purposes coincident, are the acuity curves for light-orange and yellowish green lights. Within the range of hues found in practical illuminants, color, *per se*, makes very little difference in visual acuity. The ordinates of these curves are in arbitrary units, since the purpose here is merely to analyze their shape. Their most important feature for the present purpose is that, while showing low acuity at a few meter-candles, these curves rise very slowly after reaching 20 to 30 meter-candles, although they continue to rise gradually beyond this point; so it appears that shade perception and visual acuity reach their steady state in the eye for all practical purposes at about the same point, and that this point is not far above 20 meter-candles. In other words, with this illumination the eye practically reaches its normal working condition, and beyond this point relatively little improvement can be made by providing more light.

Something, as will be seen later, depends upon the state of adaptation of the eye, that is, upon the way that it has habituated itself temporarily to working with more or less light. For example, an eye which has been working with a hundred meter-candles illumination finds itself somewhat inconvenienced temporarily in going back to 25 meter-candles, while an eye habituated to working at 10 or 15 meter-candles can do so quite comfortably and would be temporarily much inconvenienced by the glare of 100 meter-candles. The chief point to be remembered in using, as we shall see later, this physiological basis for the estimate of suitable illumination is that the meter-candles specified as necessary to bring the eye to its normal state refer to the light which the eye can derive from the objects viewed, and not merely to the intensity of the light which falls upon those objects. This is quite another matter, since the light emitted by the objects illuminated and available for the purpose in hand depends upon their reflective power, which will hereafter be taken into consideration. Broadly,

the illumination available for vision of an object is that incident upon it multiplied by its coefficient of reflection.

The term here used to define illumination is practically self-descriptive. A meter-candle of illumination means merely the illumination a meter from a standard candle. Similarly, 2 meter-candles is the illumination a meter from 2 candles, and so on. Until very recently there has been great confusion in the meaning of the term "candle" used in such connection, but in this volume when the term "candle" is employed, the present International "candle," the origin of which will be explained in Chapter IV, is the one thing meant. "Candle" when used in this book is used in this sense only. For scientific purposes the metric system is standard the world over, and no other system of units than the metric has common currency for technical purposes; hence, so far as the scientific investigation of illumination goes, the meter-candle just referred to will be employed in this volume.

Both in England and in this country the common unit of illumination referred to in the technical press is the foot-candle, rather than the meter-candle, — a unit of illumination, the derivation of which is obvious in view of what has been stated regarding the meter-candle. The writer will not hesitate to use this common term, the foot-candle, whenever it seems desirable in connection with practical computation of illumination in which the distances rather generally are most conveniently obtained in feet. The illumination a foot from a candle is written both "foot-candle" and "candle-foot," the latter term being common in English books. The terms are absolutely interchangeable, and the use of both of them can create no confusion, although the writer personally prefers and uses the former mainly on account of its more euphonious and descriptive plural. The relation between these practical units of illumination is very simple: 1 foot-candle equals 10.76 meter-candles, so that no confusion need result from the double use of terms. As will be seen later, the meter-candle is the systematic unit of illumination to which properly belongs the name *lux*.

For any light the illumination at one meter distance is obviously a number of meter-candles numerically equal to the candle power of the light.

At distances other than one meter the illuminating power is determined by the well-defined, but often misapplied, "law of inverse

squares." This law states that the intensity of light from a given source varies inversely as the square of the distance from that source. Thus, if we have a radiant point (*P*, Fig. 3), it will shine with a certain intensity on a surface *abcd* at a distance *eP*. If we go to double the distance (*EP*), the same light which fell on *abcd* now falls on the area *ABCD*, of twice the linear dimensions and four times the area, and consequently the intensity is reduced to one-fourth of the original amount. Thus if *P* be one candle and *eP* one meter, then the illumination at *e* will be one meter-candle, and at *E* one-fourth meter-candle.

This law of inverse squares is broadly true of every case of the free distribution of energy from a point within a homogeneous medium, for reasons obvious from the inspection of Fig. 3. It does

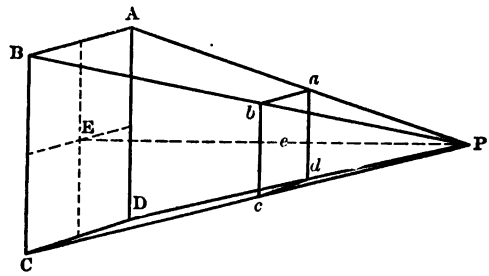


Fig. 3. — Illustrating Law of Inverse Squares.

not hold save within certain limits in considering a radiant surface as a whole, nor for any case in which the medium is not homogeneous within the radii considered.

By reason of these limitations, in problems of practical illumination the law of inverse squares can be considered only as a useful guide; for it is far from infallible, and may lead to grossly inaccurate results. It is exact only in the rare case of radiation from a minute point into space in which there is no refraction or reflection. A room with dead-black walls, lighted by a single candle, would furnish an instance in which the illumination could be computed by the law of inverse squares without an error of more than say 2 or 3 per cent, while a white-and-gold room lighted by a well-shaded arc light would illustrate an opposite condition in which the law of inverse squares alone would give a result grossly in error.

Fig. 4 shows how completely deceptive the law of inverse squares may become in cases complicated by refraction or reflection. Here one deals with an arc light of perhaps 5000 actual candle power as the source of radiation, but a very large proportion of the total luminous energy is concentrated by the reflector or lens system into a nearly parallel beam which maintains an extremely high luminous intensity at great distances from the apparatus. If the beam were actually of parallel rays its resultant illumination would be uniform at all distances, save as diminished by the absorption of



Fig. 4. — Beam from Searchlight.

the atmosphere, probably not over 10 per cent in a mile in ordinarily clear weather, since the absorption of the entire thickness of the atmosphere for the sun's light is only about 16 per cent.

The searchlight furnishes really a special case of scenic illumination, which frequently depends upon the use of concentrated beams in one form or another, so that one must realize that a very considerable branch of the art of illumination imposes conditions not reconcilable with the ordinary application of the law of inverse squares.

It is worth while thus to examine the law in question because it is a specially flagrant example of a principle, absolutely and

mathematically correct within certain rigid limitations, but partially or wholly inapplicable in many important cases.

Aside from the lux, which is little used in this country as compared with the foot-candle, there is only one generally accepted special unit employed in illuminating engineering. This is based upon the idea of luminous flux, that is, luminous energy proceeding from a point into the surrounding free space. Evidently such luminous flux determines the whole quantity of light energy which streams from a single source, diminishing in flux density per unit area as it proceeds outward. The total luminous energy evidently remains the same, whatever the total illuminated area around the source may be. Precisely this idea of flux runs through all cases of energy outflowing from a central source.

The unit of luminous flux is taken as that proceeding from a source of unit intensity throughout one unit solid angle, and is called the *lumen*. There are 4π or 12.56 such solid angles in the sphere. Now if one takes the international candle as the unit of intensity, then 1 lumen is the flux of luminous energy proceeding from a source of 1 mean spherical international candle through a unit solid angle; and in terms of flux, therefore, 1 mean spherical international candle is a source of 4π lumens. As the luminous flux proceeding outward is not increased or decreased in total amount at whatever distance it is measured, any surface subtending one unit solid angle from the source mentioned receives a total flux of 1 lumen. This total flux, divided by the area of the surface in square feet, gives the illumination in foot-candles at that surface; or, if one chooses the lux as the unit of illumination, the total flux over the area must be divided by the area in square meters to give the corresponding illumination. The foot-candle, therefore, denotes an illumination of 1 lumen per square foot and the lux an illumination of 1 lumen per square meter. This method of reckoning provides a very convenient way of getting the illumination, provided one knows or can compute the efficiency of utilization of the source reckoned upon the working plane. A table of such efficiency with various kinds of installations will be given later which will prove useful in computing the necessary intensity of the source to produce a given illumination in lumens per square foot or per square meter. Perhaps the most important use of the idea of luminous flux is in reckoning the illumination proceeding from secondary sources like bright illuminated surfaces.

The lumens incident upon these can be at once computed from the solid angle subtended by them with respect to the primary source. This determined, the secondary source becomes simply a source of a known number of lumens at a given distance from the point at which the secondary illumination is to be reckoned.*

Several systems of units connected with illumination have been from time to time proposed, but have not, save for the lux and the lumen, which are common to all of them, met with sufficient general acceptance to render discussion of them here profitable. Most actual computations of illumination are made on the basis of the intensity of the sources and their relation to the surfaces to be illuminated, or by the flux-of-light method referred to the efficiency of utilization on the working plane.

Having considered the unit strength of light and the unit strength of illumination and of luminous flux, the other fundamental of artificial lighting is the intensity of the luminous source — generally known as intrinsic brightness. Optically this has no very great or direct importance, but physiologically it is of the most serious significance, and perhaps deserves more thoughtful attention than any other factor in practical illumination. It is of the more consequence, as it is the one thing which generally receives scant consideration, and is left to chance or convenience.

By intrinsic brightness is meant the strength of light per unit area of light-giving surface. If we adopt the standard candle as the unit of light, and adhere to English measures, the logical unit of intrinsic brightness is one candle power per square inch. One then may conveniently express the brightness of any luminous surface in candle power per square inch, and thus obtain a definite basis of comparison, as in the accompanying table.

* An interesting modification of the flux-of-light method of reckoning illumination is the absorption method of Dr. McAllister (*Electrical World*, Nov. 21, 1908). This is based upon the fact that whatever the intensity of illumination in, for instance, a room, for that intensity the light sources must produce the sum of all the luminous flux absorbed at the surfaces. Now the light-absorption coefficient is the familiar quantity $(1 - k)$, and for a required flux density in foot-candles the necessary lumens equal this flux density multiplied by the area and by $(1 - k)$. Hence whenever these quantities are known for the various surfaces considered the total lumens, and hence the required candle power can be at once ascertained. This very ingenious method, which is, so to speak, the converse of the ordinary flux-of-light computation, is occasionally very useful, and its details may be found in the highly original paper to which reference has been made.

INTRINSIC BRILLIANCIES IN CANDLE POWER PER SQUARE INCH.

Source.	Brilliancy.	Notes.
Sun in zenith	600,000	Rough equivalent values, taking account of absorption.
Sun at 30 deg. elevation	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	
Flame arc	5,000	Clear globe.
Calcium light	5,000	
Magnetite arc	4,000	
Nernst "glower"	3,000	Unshaded.
Tungsten lamp	1,000–1,100	
G. E. M. lamp	750	
Quartz Mercury arc	600–1,000	
Tantalum lamp	580	
Carbon incandescent lamp	300–500	Depending on efficiency.
Melting platinum	129	
Inclosed arc	75–150	Opalescent inner globe.
Acetylene flame	40–60	
Welsbach light	20 to 40	100 or more for high-pressure gas supply.
Cooper Hewitt tube	10 to 12	
Kerosene light	4 to 9	Very variable.
Candle	3 to 4	
Gas flame	3 to 8	Very variable.
Incandescent (frosted)	2 to 8	
Opal-shaded lamps, etc.	0.5 to 2	
Moore tube	0.5 to 1	

The striking thing about this table is the enormous discrepancy between electric and other lamps of incandescence and flames of the ordinary character. The very great intrinsic brilliancy of the ordinary unshaded incandescent lamps is particularly noteworthy and, from the oculist's standpoint, menacing.

Although a measure of intrinsic brightness is obtained by dividing the candle power of any light by the area of the luminous surface, this latter quantity is very difficult to determine accurately, since with the exception of the electric incandescent filament no source of light is anywhere nearly of uniform brilliancy over its entire surface. For the sake of comparison we can, however, draw up the above approximate table by assuming equal brightness over the generally effective lighting area of any radiant. It should be distinctly understood that the values tabulated are only average values of quantities, some of which are incapable of exact determination and others of which vary over a wide range according to conditions.

Everyone is familiar with the distress caused the eye by sudden alternations of light and darkness, as in stepping from a dark room into full sunlight, or even in lighting the gas after the eye

has become habituated to the darkness. The eye is provided with a very wonderful automatic "iris diaphragm" for its adjustment to various degrees of illumination, but it is by no means instantaneous, although very prompt, in its action. Moreover, the eye after resting in darkness is in an extremely sensitive and receptive state, and a relatively weak light will then produce very noticeable after-images. These after-images, such as are seen in vivid colors after looking at the sun, are due to retinal fatigue.

If the image of a brilliant light is formed upon the retina, it produces certain very considerable chemical changes, akin to those produced by light upon sensitized paper. In so doing it temporarily exhausts or weakens the power of the retina to respond at that point to further visual impressions, and when the eye is turned away the image appears, momentarily persistent, and then reversed, dark for a white image, and of approximately complementary hue for a colored one. This after-image changes color and fades away more or less slowly, according to the intensity of the original impression, as the retina recovers its normal sensitiveness.

A strong after-image means a serious local strain upon the eye, and shifting the eye about when brilliant light can fall upon it implies just the same kind of strain that one gets in going out of a dark room into bright sunshine. The results may be very serious. In one case recently reported a strong side light from an unshaded incandescent lamp set up an inflammation that finally resulted in the loss of an eye. The light was two or three feet from the victim, whose work was such that the image of the filament steadily fell on about the same point on the retina, at which point the resulting inflammation had its focus. A few weeks' exposure to these severe conditions did the mischief. This is an extreme case, but similar conditions may very quickly cause trouble. A few years ago the writer was at lunch facing a window through which was reflected a brilliant beam from a white-painted sign in full sunlight just across the street. No especial notice was taken of this, until on glancing away a strong after-image of the sign appeared, and although the time of exposure was only ten or fifteen minutes, the net result was inability to use the eyes more than a few minutes at a time for a fortnight afterwards.

To a certain extent the eye can protect itself from the brilliant sources of light by the automatic action of the iris. This protection, however, is not rapid enough or complete enough to

guard the eye properly against the brilliant sources now in common use.

It is very difficult to get an exact idea of the reaction of the pupil to light on account of the large number of factors which enter the question and the constant slight variations to which the pupillary diameter is subject. Its diameter varies from scarcely more than 1 mm. under extreme conditions of contraction, to 7 or 8 mm. in darkness, so that to use the familiar expression applied to lens stops, it works from somewhere about $\frac{f}{16}$ to $\frac{f}{2.5}$, or even $\frac{f}{2}$, when

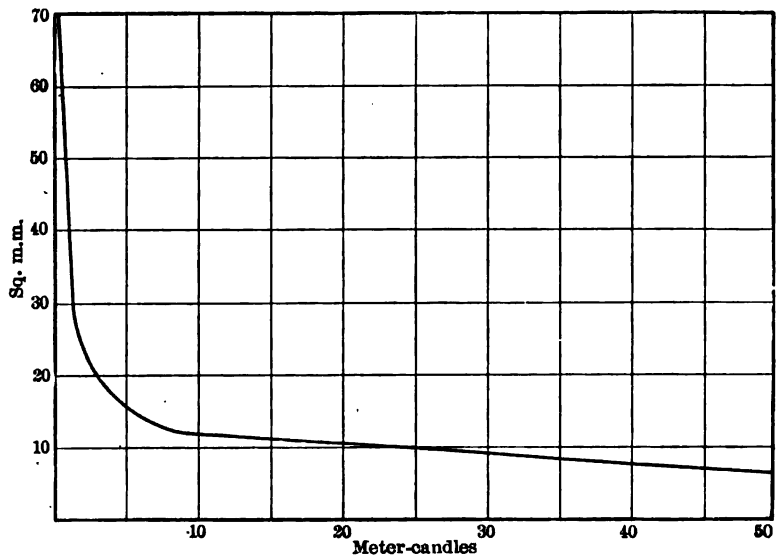


Fig. 5. — Variation of the Pupil in Different Illuminations. Plotted from early experiments by Lambert.

in darkness the expanding iris retreats clear out to the rim of the cornea. Ordinarily the pupillary diameter is in moderate light 3 or 4 mm., and the eye therefore is working at about $\frac{6}{f}$.

A rough idea of the variation of the pupil in different illuminations is given by the curve of Fig. 5, plotted from the early experiments of Lambert. The ordinates give the area of the pupil, the abscissæ the illumination, in meter-candles. It is interesting to note that most of the variation takes place under

10 meter-candles, beyond which the curve rapidly becomes asymptotic. The eye cannot, therefore, well protect itself against extremely bright sources, and seems in this, as in other particulars, to have been specialized in the course of its development for moderate degrees of illumination; nor is the protection instantaneously established. It takes about half a second for contraction or expansion to set in after a sudden change in illumination. The contraction, once begun, takes, however, less than half this time, and expansion somewhat longer. The eye, therefore, cannot effectively guard itself against sudden variations, and the result is often extremely painful.

An important question is the effect upon the pupil of such distribution of light as is commonly found in artificial illumination. Does the pupil adjust itself to the average intensity or to the intensity of the brightest point within the field of vision? This matter has been pretty thoroughly investigated, with the result of showing that upon the whole the pupil adjusts itself rather to bright lights in the central part of the field than to average illumination. It does not, however, react as fully to bright lights in the peripheral field, and thus defends itself rather inadequately against intense light coming from unwonted directions.

The presence of a bright light in full view, therefore, causes the pupil to contract, and seriously reduces the visibility of objects in the adjacent field. In ordinary seeing, where there are no brilliant sources visible, the iris opens up when the lighting is low and gives considerably increased powers of discrimination. Were it not for this, it would be exceedingly difficult to get about at night even by moonlight. In this latitude, moonlight even near full moon is hardly more than 0.2 meter-candles, which by reference to Fig. 2 would give Fechner's fraction at nearly 0.5, save for the aid received from the expanding pupil. With the pupillary area, however, increased perhaps six times, one can see to get about comfortably enough and can even read very coarse print. It should be noted here that the curves of Fig. 2 were attained by vision through a stop, so that the effective pupillary diameter was sensibly constant.

The same conditions have an important bearing on vision in presence of a brilliant light in the field. For example, suppose that in a general illumination of 1 meter-candle the eye can make out objects having a contrast $\frac{dI}{I}$ equal to 0.15. Then let a light

come into the field of vision so as to increase the illumination on the eye to 20 meter-candles without materially illuminating the objects in the vicinity. The pupil will close to about one-third of its former area under these circumstances, raising Fechner's fraction to 0.3 or thereabouts, and consequently objects having the contrast just mentioned would disappear.

Hence, as is well known, one cannot see well across a bright light, and even objects illuminated by it will lose in visibility unless the change in the illumination received by them is greater than the concomitant adverse change produced by the contraction of the pupil. In short, a bright light falling on the eye quite generally interferes with vision by decreasing the pupillary aperture, more than it helps it by added illumination upon neighboring objects.

A very simple experiment, showing this effect of a strong source of light on the apparent illumination, may be tried as follows: Light a brilliant lamp, unshaded, in a good-sized room, preferably one with darkish paper. Then put on the light an opal or similar shade. It will be found that the change has considerably improved the apparent illumination of the room, although it has really cut off a good part of the total light. Moreover, at points where there remains a fair amount of illumination, the shade has improved the reading conditions very materially. If one is reading where the unshaded light is at or within the edge of the field of vision, the improvement produced by the shade is very conspicuous. Lowering the intrinsic brilliancy of the light has decreased the strain upon the eye and given it a better working aperture.

As a corollary to these suggestions on the effect of bright lights on our visual apparatus should be mentioned the fact that sudden variations in the intensity of illumination seriously strain the eye both by fatigue of the retina, due to sudden changes from weak to strong light, and by keeping the eye constantly trying to adjust itself to changes in light too rapid for it properly to follow.

A flickering gaslight, for example, or an incandescent lamp run at very low frequency, strains the eye seriously and is likely to cause temporary, even if not permanent, injury.

The persistence of visual impressions whereby the retinal image remains steady for an instant after the object ceases to affect the eye furnishes a certain amount of protection in case of very rapid changes of brilliancy. It acts like inertia in the visual system.

In the case of arc and incandescent lamps, the thermal inertia of

the filament or carbon rod also tends physically to minimize the changes, but with a low-frequency alternating current they may still be serious.

The exact frequency at which an incandescent lamp on an alternating circuit begins to distress the eye by the flickering effect depends somewhat on the individual eye and somewhat on the mass of the filament. In general, a 16-c.p. lamp of the usual voltages, say 100 to 120 volts, begins to show flickering at or sometimes a little above 30 cycles per second; one foreign authority noting it even up to 40 cycles. At 25 cycles the flickering is troublesome to most eyes, and at 20 cycles or below it is generally quite intolerable. In looking directly at the lamp the filament is so dazzling that the fluctuations are not always in evidence at their full value, and a low-frequency lamp is quite likely to be the source of trouble to the eye even when at first glance it appears to be quite steady. The metallic filament lamps from their small thermal inertia are more sensitive to these effects than carbon-filament lamps.

Lamps having relatively thick filaments can be worked at lower frequencies than those of the common sort, so that 50-volt lamps, particularly of large candle power, may be worked at 30 cycles or thereabouts rather well, and out of doors even down to 25 cycles. That is, at a pinch one can do satisfactory work when current is available at 25 cycles or so, by using low-voltage lamps of 32, 50, or 100 candle power, which, by the way, are capable of giving admirable results in illumination if properly disposed. Of course, such practice is bad in point of efficient distribution of current, but on occasion it may be useful.

As to arc lamps, conditions are not so favorable. The fluctuations of an alternating arc lamp are easily detected, even at 60 cycles, by moving a pencil or the finger quickly when strongly illuminated. The effect is a series of images along the path of motion, corresponding to the successive maxima of light in the arc. At 40 to 45 cycles the flickering becomes evident even when viewing stationary objects, the exact point where trouble begins depending upon the adjustment of the lamp, the hardness of the carbons, and various minor factors. Inclosing the arc mitigates the difficulty somewhat, but does not remove it.

In working near the critical frequency the best results are attained by using an inclosed arc lamp taking all the current the inner globe will stand, with as short an arc as will work

steadily. Flaming arcs perform rather better on account of the large mass of light-giving vapor.

When polyphase currents are available, as is usually the case where rather low frequencies are involved, some relief may be obtained by arranging the arcs in groups consisting of one from each phase. At a little distance from such a group the several illuminations blend so as to partially suppress the fluctuations of the individual arcs. This device makes it possible to obtain fairly satisfactory lighting between 35 and 40 cycles. At these frequencies, however, the arcs should not be used except when a very powerful light is necessary, or when the slightly yellowish tinge of incandescents would interfere with the proper judgment of colors. Powerful incandescents are generally better, and are, now that large tungsten lamps are available, quite as efficient, particularly when one takes into account proper distribution of the light. In using incandescents in large masses, particularly on polyphase circuits, the flickering of the individual lights is lost in the general glow, so that even at 25 cycles the light may be steady enough for general purposes, as was the case with the decorative lighting at the Pan-American Exposition. The fluctuations due to low frequency are usually very distressing to the eye, and should be sedulously avoided. Fortunately, save in rare instances, the frequency can be and should be kept well above the danger point.

The same considerations which forbid the use of very intense lights, unshaded; flickering lights; and electric lights at too low frequency, render violent contrasts of brilliant illumination and deep shadows highly objectionable. It should be remembered that in daylight the general diffusion of illumination is so thorough that such contrasts are very much softened, even in full sunlight, and much of the time the direct light is modified by clouds. In situations where the sun shines strongly down through interstices in thick foliage, the effect is decidedly unpleasant if one wishes to use the eyes steadily; and if, in addition, the wind stirs the leaves and causes flickering, the strain upon the eyes is most trying.

In artificial lighting one should carefully avoid the conditions that are objectionable in nature, which can easily be done by a little foresight. If for any purpose very strong illumination becomes necessary at a certain point, the method of furnishing it

which is most satisfactory from a hygienic standpoint is to superimpose it upon a moderate illumination well distributed. If a brilliant light is needed upon one's work, start with a fairly well-lighted room and add the necessary local illumination, instead of concentrating all the light on one spot. This procedure avoids dense shadows and dark corners, and enables the eye to work efficiently in a much stronger illumination than would otherwise be practicable.

It should not be understood that the complete abolition of shadows is desirable. On the contrary, since much of our perception of form and position depends upon the existence of shadows, the entire absence of them is troublesome and unpleasant. This is probably due to two causes. First, the absence of shadows gives an appearance of flatness out of which the eye vainly struggles to select the wonted degrees of relief. In a shadowless space we have to depend upon accommodation and binocular vision to locate points in three dimensions, and the strain upon the attention is severe and quickly felt.

Second, the existence of a shadowless space presupposes a nearly equal illumination from all directions. If it be strong enough from any particular direction to be convenient for work requiring close attention of mind and eye, then, if there be no shadows, equally strong light will enter the eye from directions altogether unwonted. This state of things we have already found to be objectionable in the highest degree.

The best illustration of this unpleasant condition may be found in nature during a thin fog which veils the sun while diffusing light with very great brilliancy. Try to read at such a time out of doors, and, although there is no direct light on the page to dazzle you, and there is in reading no trouble from the sense of flatness, yet there is a distinctly painful glare which the eyes cannot long endure without serious strain.

In artificial lighting the same complete diffusion is competent to cause the same results, so that while contrasts of dense shadows and brilliant light must be avoided, it is generally equally important to give the illumination, even if deliberately indirect, a certain general direction to relieve the appearance of flatness and to save the eye from cross lights.

With respect to the best direction of illumination, only very general suggestions can be given. Brilliant light, direct or re-

flected, should be kept out of the eye and upon the objects to be illuminated. In each individual case the nature and requirements of the work must determine the direction of lighting.

The old rule given for reading and writing, that the light should come obliquely over the left shoulder, well illustrates ordinary requirements. By receiving the light from the point indicated direct light is kept out of the eyes, and any light regularly reflected is generally out of the way. The eye catches then only diffused light from the paper before it, and if the light comes from the left (for a right-handed person) the shadow of hand and arm does not interfere with vision in writing. If work requiring both hands is under way, the chances are that the best illumination will be obtained by directing it downwards and slightly from the front, in which case care must be exercised to avoid strong direct reflection into the eyes. The best simple rule is, avoid glare direct or reflected, avoid strong shadows, and get ample diffused light from the object illuminated.

This brings us at once to the very important but ill-defined question of the strength of illumination required for various kinds of work.

Fortunately, the eye works well over a wide range of brightness, but there is a certain minimum illumination which should be exceeded if one is to work easily and without undue strain. The matter is much complicated by questions of texture and color, which will be taken up presently, so that only general average results can be considered. For reading and writing, experience joins the physiological data already given in showing that an intensity of at least 10 meter-candles is the minimum amount for ordinary type and ink, such as is here used, for instance. With large, clear type,

like that used for this particular line,

5 or 6 enable one to read rather easily; while with ordinary type set solid or in type of the smaller sizes,

such type as is employed in this line as a horrible example,

30 or 40 meter-candles is by no means an unnecessary amount of lighting. Dense black ink and clear white paper not highly calendered, such as some of the early printers knew well how to use, make vastly easier reading than the grayish-white stuff and cheap, muddy-looking ink to be found in the average newspaper.

Illumination of less than 10 usually renders reading somewhat difficult and slow, the more difficult and slower as the illumination is further reduced. At 2 or 3 meter-candles reading is by no means easy, and there is a strong tendency to bring the book near the eye, thereby straining one's power of accommodation, and to concentrate the attention upon single words, a tendency which increases as the light is still further lessened.

In fact, when the illumination falls to the vicinity of 1 meter-candle it is of very little use for the purpose of reading or working.

One may get a fair idea of the strength of illumination required for various purposes by a consideration of that actually furnished by nature. To get at the facts in the case, we must make a little digression in the direction of photometry, a subject which will be more fully discussed later.

To get an approximate measure of the illumination furnished by daylight, one can conveniently use what is known as a daylight photometer. This instrument furnishes a means for balancing the illumination due to any source against that due to a standard candle at a known distance. Like most common forms of photometer, it consists of a screen illuminated on its two sides by the two sources of light respectively. Equality of illumination is determined by the disappearance of a grease spot upon the screen. A spot of grease on white paper produces, as is well known, a highly transparent spot, which looks bright if illuminated from behind, and dark when illuminated from the front.

Thus, if one sets up such a screen *C* between, and equi-distant from, a candle *A* and an incandescent lamp *B*, and then looks at the screen obliquely from the same side as *B*, the appearance is that shown in Fig. 6. Moving around to the other side of the screen, one gets the effect shown in Fig. 7. By moving the candle *A* nearer or the incandescent *B* farther off, a point will be found where the spot becomes nearly invisible on account of the equal illumination on the two sides. This "Bunsen photometer screen" requires very careful working to get highly accurate results, but gives closely approximate figures readily. The daylight photometer, Fig. 8, is the simplest sort of adaptation of this principle. It consists of a box, say 5 or 6 feet long and 15 inches square. In one end is a hole *B* filled with the photometer screen just described, and a slot to receive a graduated scale *A* carrying a

socket for a standard candle. The interior of the box is painted dead black, so as to avoid increasing the illumination at *B* by light reflected within the box.

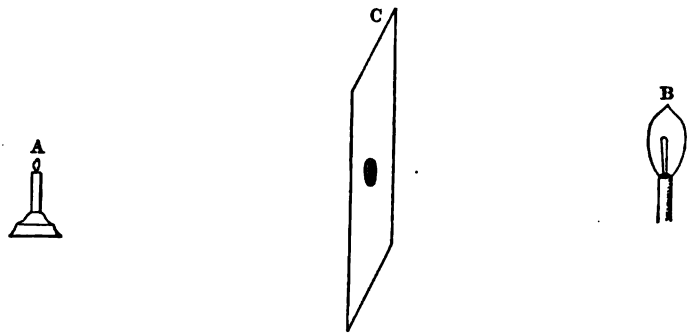


Fig. 6. — Principle of the Photometer.

Setting up the box with the end *B* pointing in the direction of the illumination to be estimated, the candle is slid back and forth until the grease spot disappears, when the distance from the candle to *B* gives the required illumination, by applying the law of

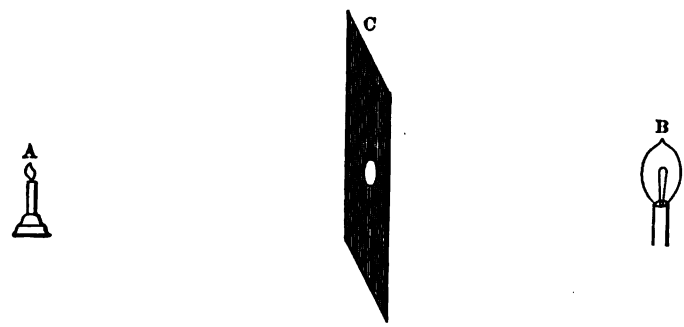


Fig. 7. — Principle of the Photometer.

inverse squares, which holds sufficiently well for approximate purposes if the box is well blackened.

Of course the results of such measurements vary enormously with different conditions of daylight. A few measurements made in a large, low room with windows on two sides, culled from the

writer's notebook, give the following results, the day being bright, but not sunny, and the time early in the afternoon:

Facing south window	64	meter-candles.
Facing east window	24	" "
Facing north wall	7.5	" "
And again, 10 feet from south window, on a misty April day, 5 P.M.	5.3	" "

On a clear day the diffused illumination near a window, while the sun is still high, will generally range from 50 to 60 meter-candles, while in cases where there are exceptionally favorable conditions for brilliant illumination it may rise to twice or even four times the amount just stated. The intrinsic brilliancy of an aperture fully exposed to the upper sky is, for a yearly average, according to the measurements of Dr. Basquin, about 0.4 candle power per square centimeter, which enables the illumination to be roughly estimated in simple cases.



Fig. 8. — Daylight Photometer.

Now, these figures for the lighting effects of diffused daylight give a good clew, if nothing more, to the intensity of illumination required for various purposes. In point of fact, reading and writing require less light than almost any other processes which demand close ocular attention. Everything is black and white, there is no delicate shading of colors, nor any degrees of relief to be perceived in virtue of differences of light and shade. Moreover, the characters are sharply defined and not far from the eye. It is therefore safe to say that for even the easiest work requiring steady use of the eyes at least 10 meter-candles are demanded. In general, this minimum should be at least doubled for really effective lighting, while for much fine detail and for work on colored materials not less than 50 meter-candles should be pro-

vided. Even this amount may advantageously be doubled for the finest mechanical work, such as engraving, watch repairing, and similar delicate operations. In fact, for some such cases the more light the better, provided the source of light and direct undiffused reflections therefrom are kept out of the eyes.

These estimates have taken no account of the effect of color, which sometimes is a most important factor, alike in determining the amount of illumination necessary and in prescribing the character and arrangement of the sources of light to be employed.

CHAPTER II.

PRINCIPLES OF COLOR.

THE relation of color to practical illumination is somewhat intricate, for it involves considerations physical, physiological, and æsthetic; but it is well worth studying, for while in some departments of illumination, such as street lighting, it is of little consequence, in lighting interiors it plays a very important part. In lighting a shop where colored fabrics are displayed, for example, it is necessary to reproduce as nearly as may be the color values of diffused daylight, even at considerable trouble. Such illumination, however, may be highly undesirable in lighting a ballroom, where the softer tones of a light richer in yellow and orange are generally far preferable.

In certain sorts of scenic illumination strongly colored lights must be employed, but always with due understanding of their effect on neighboring colored objects. Sometimes, too, the natural color of a light needs to be slightly modified by the presence of tinted shades, serving to modify both the intrinsic brilliancy and the color.

The fundamental law with respect to color is as follows: *Every opaque object assumes a hue due to the sum of the colors which it reflects.* A red book, for instance, looks red because from white light it selects mainly the red for reflection, while strongly absorbing the green and blue.

White light, as a look through a prism plainly shows, is a composite of many colors, fundamentally red, green, and blue, incidentally of an almost infinite variety of transition tints. If a narrow beam of sunlight passes through a prism, it is drawn out into a many-colored spectrum in which the three colors mentioned are the most prominent. Closer inspection detects a rather noticeable orange region passing from red to green by way of a narrow space of pure yellow, which is never very conspicuous. The green likewise shades into pure blue through a belt of greenish blue, and the blue in turn shades off into a deep violet. If the slit which admits the sunlight is made very

narrow, certain black lines appear crossing the spectrum, — the Fraunhofer lines due to the selective absorption of various substances in the solar atmosphere. These lines are for the purpose in hand merely convenient landmarks to which various colors may be referred. They were designated by Fraunhofer by the letters of the alphabet, beginning at the red end of the spectrum.

Fig. 9 shows in diagram the solar spectrum with these lines and the general distribution of the colors. The *A* line, really a broad dark band of many lines, is barely visible save in the most intense light, and the eye can detect little or nothing beyond it. At the other end of the spectrum the *H* lines are in

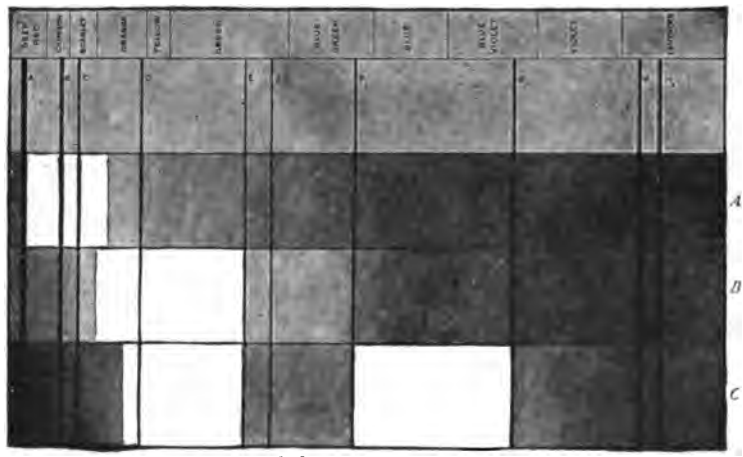


Fig. 9. — Solar and Reflected Spectra.

a violet merging into lavender, are not easy to see, and there is but a narrow region visible beyond them, — pale lavender, as generally seen. The spectrum in Fig. 8 is roughly mapped out to show the extent of the various colors as distributed in the ordinary prismatic spectrum.

At *A*, Fig. 9, is shown the spectrum of the light reflected from a bright-red book, i.e., the color spectrum which defines that particular red. It extends from a deep red into clear orange, while the absorption in the yellow and yellowish green is by no means complete.

At *B* is the color spectrum from a green book. Here there is considerable orange and yellow, a little red and much bright green, together with rather weak absorption in the bluish green.

C shows a similar diagram from a book apparently of a clear, full blue. The spectrum shows pretty complete absorption in the red and extending well into the orange. The orange-yellow and yellowish green remain, however, as does all the deep blue, while there is a perceptible absorption of the green and bluish green.

Now, these reflected spectra are thoroughly typical of those obtained from any dyed or painted surfaces. The colors obtained from pigments are never the simple hues they appear to be, but mixtures more or less complex sometimes of colors from very different regions of the spectrum. Most of the commoner pigments produce absorption over rather wide regions of the spectrum, but some of the delicate tints found in dyed fabrics show several bands of absorption in widely separated portions of the spectrum. These are the colors most seriously affected by variations in the color of the illuminant when viewed by

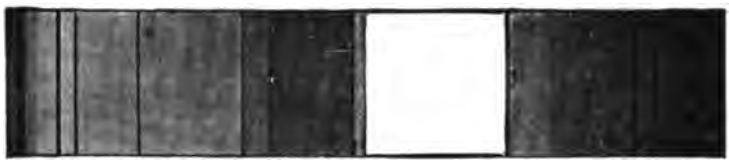


Fig. 10. — Spectrum Reflected from Blue Silk.

artificial light. Fig. 10 is a case in point, a color spectrum taken from a fabric which in daylight was a delicate cornflower blue. The absorption begins in the crimson, leaving much of the red intact, is partial in the orange and yellow, stronger in the green, and quite complete in the bluish-green region. The blue well up to the violet is freely reflected, and then the violet end of the spectrum is considerably absorbed. Most of the reflected light is blue, but if the illumination is conspicuously lacking in blue rays, as is the case with candlelight or common gaslight, the blue light reflected is necessarily weak, while the red component comes out at its full strength, and the visible color of the fabric is distinctly reddish.

A similar condition is met in certain blues which in daylight reflect a large proportion of blue and bluish violet, but in which some green rays are left, just as was the clear red in Fig. 10. By gaslight the blue becomes relatively very much weakened, and the apparent color is unmistakably green. Such changes in hue are in

greater or less degree very common, and furnish some very curious effects. Sometimes a color clear by daylight appears dull and muddy by artificial light, and in general the quality of the illumination requires careful attention whenever one deals with delicate colors.

The absorption found in the pigments used in painting is seldom so erratic as that shown in Fig. 10, but pictures often show very imperfectly under ordinary artificial illumination.

It is no easy matter to get a clear idea of the color properties of various illuminants. Of course, one can form spectra from each of the lights to be compared, and compare the relative strengths of the red, green, blue, and other rays in each; but this gives but an imperfect idea of the relative color effects produced, for the results themselves are rather discordant, and the relative brightness thus measured does not correspond accurately with the visual effect. Lights have also been extensively compared by color-mixing devices using colored screens to segregate red, green, and blue portions of the spectrum which are then varied to match the color under investigation. The results are valuable *inter se*, but lack the definiteness secured by using the spectral colors. Probably a better plan from the standpoint of illumination is to match the visible color of a given illuminant accurately by mixtures of the three primary spectral colors, red, blue-violet, and green, and to determine the exact proportions of each constituent required to give a match. Even this evidently does not tell the whole story, but it gives an excellent idea of the color differences found in various lights. Such work has been very beautifully carried out by Abney, from whose results the following table is taken:

	Sunlight.	Sky light.	Arc light.	Gaslight.
Red	100	100	100	100
Green	193	256	203	95
Violet	228	760	250	27

Incandescent lamps are not here included, but give enormously different results according to the degree of incandescence to which they are carried. If burned below candle power, they give a light not differing widely from gaslight; while if pushed far above candle power, the light is far richer in violet rays, and becomes approxi-

mately white. Unfortunately, however, the lamp does not reach this point save at a temperature that very quickly ends its life.

The effects of the selective absorption which so deceives the eye when colored objects are viewed in colored lights are shown in a variety of ways according to the colors involved, but the net result of them all is to show the necessity of looking out for the color of artificial lights. Of course, a really strong color may produce very fantastic results. For example, in the rays of an ordinary green lantern, such as is used for railway signals, greens generally appear of nearly their natural hues; but greens, yellows, browns, and grays all match pretty well, although they may appear darker or lighter in shade. Pink looks gray, darkening in shade as it is redder, and red is nearly black, for the green light which falls upon it is almost totally absorbed.

Practical illuminants do not often present so violent deceptions, and yet gas or candle light is certain to change the apparent hue of any delicate colors containing bluish-green, blue, or violet rays. An old Welsbach mantle which gives a light of a strongly greenish cast is pretty certain to change the color of everything not green upon which it falls. Incandescent electric lights affect colors in much the same way as brilliant gaslight, while arc lights give a fair approximation to daylight. It by no means follows, however, that all colors should be matched by arc lights in preference to other sources of illumination. A match so made stands daylight, but may be most faulty when viewed by gaslight.

If matching colors has to be done, it is a safe rule to match them by the kind of light by which they are intended to be viewed. Moreover, different shades of the same color are differently affected in artificial light. As a rule, deep, full colors are far less affected than light tones of the same general hue. Clear yellows, reds, and blues not verging on green are usually little altered, but pale pinks, violets, and "robin's-egg" blues quite generally suffer. Very often when a color is not positively altered it is made to appear gray and muddy.

For while in a green light greens look particularly brilliant, red may be practically extinguished, absorbing all the rays which come to it, so that a deep red will be nearly black, and a very light red merely a dirty white, tinged with green if anything.

Quite apart from any effect of colored illumination, colors seem to change in very dim light. This is a purely physiological matter,

the eye itself differing in its sensibility to different colored lights. In very faint illumination no color of any kind is perceptible—everything appears of uncertain shades of gray. As the light fades from its normal intensity, as in twilight, red disappears first, then violet and deep blue follow, settling like the red into murky blackness; then the bluish green and green shade off into rapidly darkening gray, and finally the yellow and yellowish green lose their identity and merge into the night. At the same time the hues even of simple colors change, scarlet fading into orange, orange into yellow, and green into bluish green.

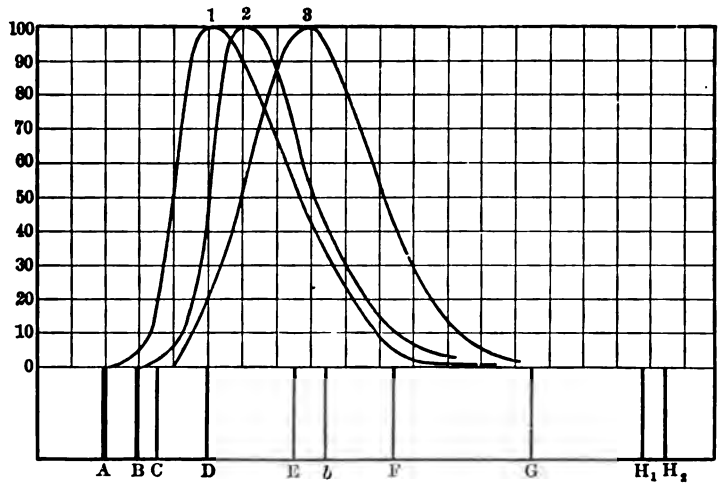


Fig. 11. — Effect of Faint Light on Color.

Obviously, complicated composite colors must vary widely under such circumstances, for as the light grows dimmer their various components do not fade in equal measure. Pinks, for instance, generally turn bluish gray at a certain stage of illumination, owing to the extinction of the red rays. In fact, in a dim light the normal eye is color-blind as regards red, and one can get a rather good idea of the sensations of the color-blind by studying a set of tinted wools or slips of paper in the late twilight.

The similarity of the conditions is strikingly illustrated in Fig. 11, which shows in No. 1 the distribution of luminosity in the spectrum of bright white light to the normal eye, and in No. 2 the luminosity of the same as seen by a red-blind eye. No. 3 shows

the luminosity of the spectrum when reduced to a very small intensity and seen by the normal eye. The data are from Abney's experiments, and the intensity of No. 3 was such that the yellow component of the light corresponding to *D* of the spectrum was 0.006 foot-candle. The ordinates of No. 2 and No. 3 have been multiplied by such numbers as would bring their respective maxima to equal the maximum of No. 1, as the purpose is to show their relative shapes only. The "red-blind" curve No. 2 shows very faint luminosity in the scarlet and orange and absence of sensation in the crimson, while the maximum luminosity is in the greenish yellow. It is easy to see that the sensation of red is practically obliterated.

But in No. 3 every trace of red is gone, and the maximum brilliancy has moved up into the clear green of the spectrum at the line *E*. With a still further reduction of intensity, the spectrum would fade into gray as just noted, while a slight increase of light would cause No. 3 closely to approximate No. 2.

Starting with the normal curve of luminosity No. 1, the peak of the curve being one candle power, the light at *B* would disappear if the illumination were reduced to 0.01 of its initial value, that at *C* at about 0.0011, at *D* 0.00005, at *E* 0.0000065, at *F* 0.000015, and at *G* 0.0003.

Now the practical application of these facts is manifold. Not only do they explain the odd color effects at twilight and dawn, but it is worth noting that the cold greenish hue of moonlight on a clear night means simply the absence of the red and orange from one's perception of a very faint light; for dim moonlight is ordinarily not much brighter than would give curve No. 3. For the same reason a red light fades out of sight rather quickly, so that a signal of that color is not visible at a distance at which one of another color and equal brightness would be easily seen.

Not only is the eye itself rather insensitive to red, but the luminosity of the red part of the spectrum of any light is rather weak, so that when the other rays are cut off by colored glass the effective light is greatly reduced. About 87 per cent of the effective luminosity of white light lies between the lines *C* (scarlet) and *E* (deep green), the relative luminosities at various points being about as follows:

Line.	Luminosity.
B	3
C	20
D	98.5
E	50
b	35
F	7
G	0.6

The luminosities of light transmitted through ordinary colored glasses of various colors is about as follows, following Abney's experiments, clear glass being 100:

Color of Glass.	Light Transmitted.
Ruby	13.1
Canary	82.0
Bottle green	10.6
Bright green (signal green No. 2)	19.4
Bluish green (signal green No. 1)	6.9
Cobalt blue	3.75

These figures emphasize the need of a very powerful source, if it is necessary to get a really bright-colored light. It is worth noting that red in itself is a particularly bad color for danger signals on account of its low luminous effect, and were it not for the danger of changing a universal custom and the selective effects of atmospheric absorption, red should be the "clear" signal and green the danger signal, the latter color giving a much brighter light, and thus being on the average more easily visible. In fact, so-called red signal lights transmit the orange very freely, also the yellow, and even a little yellowish green, a pure deep red having so slight luminosity as to be quite impracticable. To obtain the necessary contrast the "green" signals usually verge upon blue-green to the detriment of their brilliancy.

It is easy to see that any artificial illuminant is at a considerable disadvantage if at all strongly colored; for not only does a preponderance of red or green rays injure color perception, but the luminosity of such rays is generally rather low, and they do not compensate for their presence by giving greatly increased illumination.

Owing to this fact the effective illumination derived from ordinary sources of light is quite nearly proportional to the intensity of the *yellow* component of each. Crova has based on this rule an ingenious approximate method of comparing the total intensity of colored lights by comparing the intensities of their yellow rays,

either from their respective spectra or by sifting out all but the yellow and closely adjacent rays by means of a colored screen.

Certainly for practical purposes the rays at the ends of the spectrum are not very useful. So far as the ordinary work of illumination goes, white or yellowish-white light is desirable, and the only practical function of strongly colored lights is for signaling and scenic illumination.

The general effect of strongly colored lights is to accentuate objects colored like the light and to change or dim all others. Lights merely tinted produce a similar effect in a less degree. Bluish and greenish tinges in the light give a cold, hard hue to most objects, and produce on the face an unnatural pallor; in fact, on the stage they are used to give in effect the pallor of approaching dissolution. Naturally enough such light is unfitted for domestic illumination, as, aside from its effect on persons, it makes a room look bare, chill, and unfurnished. In a less degree a similar effect is produced by moonlight, which, from a clear sky, is distinctly cold, the white light growing faintly greenish blue as its diminishing intensity causes the red to disappear.

On the other hand, a yellow-orange tinge in the light seems to soften and brighten an interior, giving an effect generally warm and cheery. This result is extremely well seen in stage firelight effects. Strongly red light is, however, harsh and trying, so that it should generally be carefully avoided.

While it is not easy to predict accurately the effect of tinted lights upon various delicate shades without a careful study of the light rays forming each, the average effects relating to the simpler colors are summarized in the following table. It is compiled from the experiments of the late M. Chevreul, for many years director of the dye works of the Gobelins tapestries. The colored lights were from sunlight sifted through colored glass, and the effects were upon fabrics dyed in plain, simple colors.

The facts set forth in this table show well what should be avoided in colored illumination. As regards various shades of the same colors, it must be remembered that light shades are merely the full, deep ones diluted with white, which is itself affected by the color of the incident light. In a general way, therefore, one can use this table over a wider range than that written down.

For instance, a very light red in blue light would look blue

with a mere trace of violet, while in yellow light it would be bright yellow with a very slight orange cast. Generally, a very light color viewed by colored light will be between the effect produced on the full color, and that produced by the light on a white surface. Similarly, a light faintly tinged with color will only slightly modify the tone of a colored object in the direction indicated for the full-colored light in the table.

Original Color of Fabric.	Color of Light Falling upon Fabrics.					
	Red.	Orange.	Yellow	Green.	Blue.	Violet.
Black	Purplish black	Deep maroon	Yellow-olive	Greenish brown	Blue-black	Faint violet-black
White	Red	Orange	Light yellow	Green	Blue	Violet
Red	Intense red	Scarlet	Orange	Brown	Violet	Red-violet purple
Orange	Orange-red	Intense orange	Yellow-orange	Faint yellow slightly greenish	Brown slightly violet	Light red
Yellow	Orange	Yellow-orange	Orange-yellow	Yellowish green	Green	Brown tinged with faint red
Light green	Reddish gray	Yellow-green	Greenish yellow	Intenser green	Blue-green	Light purple
Deep green	Reddish black	Rusty green	Yellowish green	Intenser green	Greenish blue	Bluish gray
Light blue	Violet	Orange-gray	Yellowish green	Green-blue	Vivid blue	Violet-blue
Deep blue	Violet-purple	Gray slightly on orange	Green-slate	Blue-green	Intenser blue	Bright blue-violet
Indigo blue	Purple slightly violet	Orange-maroon	Orange-yellow (very dull)	Dull green	Dark blue-indigo	Deep blue-violet
Violet	Purple	Red-maroon	Yellow-maroon	Bluish green-brown	Deep bluish violet	Deep violet

But delicate shades from modern dyestuffs, which often absorb the light in very erratic ways, as in Fig. 10, are a different matter, and do not obey any simple laws. On the other hand, pure colors, in the sense in which the scarlet around the *C* line of the spectrum is pure, act in a fashion rather different from that shown in the table, which pertains to standard dyestuffs which never are anywhere near being pure colors. However, as arti-

ficial illumination has to do only with commercial pigments and dyes, the table serves as a useful guide in judging the effects produced on interior furnishings by change in the color of the light.

Of common illuminants, none except for the mercury arc and the flame arc have any very decided color, yet most are somewhat noticeably tinged. One can tabulate them roughly as follows:

Illuminant.	Color.
Sun (high in sky).	White.
Sun (near horizon).	Orange-red.
Sky light.	Very bluish white.
Electric arc (short).	White.
Electric arc (long).	Bluish white to violet.
Flame arc.	Commonly, yellow.
Mercury arc.	Bluish green.
Nernst lamp.	Yellowish white.
Tungsten lamp.	Yellowish white.
Incandescent (normal), carbon.	Yellowish.
Incandescent (below voltage), carbon.	Orange to orange-red.
Acetylene flame.	Yellowish white.
Welsbach light.	Yellowish to greenish white.
Gaslight (Siemens burner).	Whitish yellow tinge.
Gaslight, ordinary.	Yellowish to pale orange.
Kerosene lamp.	Yellowish to pale orange.
Candle.	Orange-yellow.

Outside the earth's atmosphere the sun would look distinctly blue, while its light, after thorough absorption in the earth's atmosphere, gets the blue pretty completely sifted out, so that the light from the eclipsed moon, once refracted by the earth's atmosphere and then reflected through it again, is in color a deep coppery red.

Arc lights vary much in color, from clear white in short arcs with comparatively heavy current to bluish white or whitish violet in long arcs carrying rather small current. The modern inclosed arcs err in the latter direction, and give tolerable color effects only with yellowish white inner globes or shades. Incandescents, as generally worked, verge upon the orange. Of the luminous flames in use, only acetylene comes anywhere near being white, although the powerful regenerative burners are a close second. Incandescent gas lamps, at first showing nearly white with a very slight greenish cast, ordinarily acquire a greenish or yellowish-green tinge after burning for some time.

It is evident, then, that a study of the color effects produced

by colored illuminants is by no means irrelevant, for distinct tinges of color are the rule rather than the exception.

But this is not at all the whole story, for the general color of the illumination in a given space depends not only on the hue of the illuminant, but upon the color of the surroundings. Colored shades, of course, are in common use; sometimes with a definite purpose, more often from a mistaken notion of prettiness. Used intelligently, as we shall presently see, they may prove very valuable adjuncts in interior illumination.

But far more important than shading is the modification in the color of the light which comes from selective reflection at surfaces upon which the light falls. In every inclosed space light is reflected in one way or another from all the bounding surfaces, and at each reflection not only is the amount of light profoundly modified, but its color may undergo most striking changes. It is this phenomenon that gives its greatest interest to the study of color in illumination. Its importance is not always readily recognized, for few persons pay really close attention to the matter of colors, but now and then it obtrudes itself in a way that forces attention.

Take for example a display window lined with red cloth and brightly illuminated. Passing along the sidewalk, one's attention is immediately drawn to a red glow upon the street, while the lights themselves may be ordinary gas jets. To get at the significance of this matter, we must take up the effect of reflection and diffusion in modifying the amount and quality of light.

CHAPTER III.

REFLECTION AND DIFFUSION.

To begin with, reflection is of two kinds — in their essence the same, yet exhibiting very different sets of properties. The first, regular or specular reflection, may be best exemplified by the reflection which a beam of light undergoes at the surface of a mirror. The beam strikes the surface and is reflected therefrom in form as sharp and as distinct as it was before its incidence, and in a perfectly definite direction.

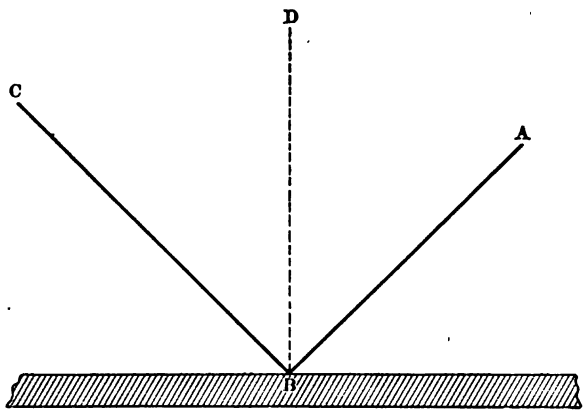


Fig. 12. — Regular Reflection.

The character of this regular reflection is very clearly shown in Fig. 12. Here *B* is the reflecting surface — a plane, polished, bit of metal, for instance. *AB* is the incident ray and *BC* the reflected ray. In such reflection two principal facts characterize the nature of the phenomenon. In the first place, if a perpendicular to the surface of the mirror — as *BD* — is erected at the point of incidence, the angle *ABD* is always precisely equal to the angle *DBC*. In other words, *the angle of incidence is equal to the angle of reflection*, which is the first law of regular reflection. Moreover, *the incident ray AB, the normal to the surface at the point of incidence BD, and the reflected ray BC are all in the same plane.*

In this ordinary form of reflection, such as is familiar in mirrors, the direction of the reflected ray is entirely determinate, and, in general, although the reflected ray has lost in intensity, it is not greatly changed in color. A polished copper surface, to be sure, shows a reddish reflection, and polished gold a distinctly yellowish reflection. Only in certain dyestuffs which exhibit a brilliant metallic reflection is the color strongly marked. In other words, a single reflection from a good, clean, specularly reflecting surface does not usually very greatly change either the intensity or the color of the reflected beam. The angle of incidence affects the brilliancy of the reflection somewhat, but the color only imperceptibly. In the art of practical illumination regular reflection comes into play only in a rather helpful way, and kindly refrains from complicating the situation with respect to color or intensity.

The second sort of reflection is what is technically known as diffuse reflection. This term does not mean that the phenomenon itself is of a totally different kind from regular reflection, but, nevertheless, its results are totally different. No surface is altogether smooth. Even with the best polished metallic mirrors, while the reflected image is perfectly distinct at ordinary angles of reflection, it is apt to become slightly hazy at grazing incidence — that is, when the incident and reflected beams are nearly parallel to the surface. This simply means that under such conditions the infinitesimal roughness of the reflecting surface begins to be in evidence.

To get an idea of the nature of diffuse reflection, examine Fig. 13. In this case a section of the reflecting surface is rough, showing grooves and points of every description — in fact, nearly everything except a plane surface. Consider now the effect of a series of parallel incident beams — numbered in the figure from 1 to 10 — falling upon the surface. Each one of them is reflected from its own point of incidence in a perfectly regular manner; yet the reflected rays, on account of the irregularity of the surface, lie in all sorts of directions and, moreover, in all sorts of planes, according to the particular way in which the surface at the point of incidence is distorted. Diffuse reflection, therefore, scatters the incident beam in all directions, for the roughnesses of an unpolished surface are generally totally devoid of any regularity. The spot upon which a beam falls, therefore, radiates

light in a diverging cone and behaves as if it were really luminous.

Some consideration of the nature of this diffuse reflection will bring to light a fact which in itself seems rather surprising: namely, that the total intensities of the two kinds of reflection are not so different from each other as might appear probable at first thought — provided the roughness of the unpolished surface is not on too small a scale; for each of the incident rays in Fig. 13 is reflected from the surface just as in the case of Fig. 12, in a perfectly clean, definite, way, and there is no intrinsic reason why the intensity of this elementary ray should be any more diminished than in the case of regular reflection.

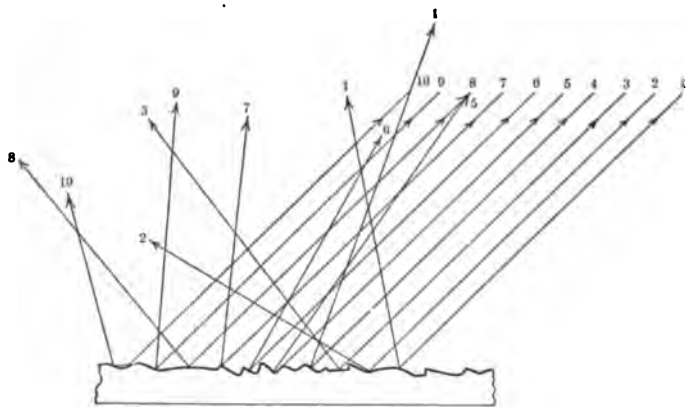


Fig. 13. — Diffuse Reflection.

A little inspection of Fig. 13, however, shows that rays Nos. 5 and 10 are twice reflected before they get fairly clear of the surface, and if one went on drawing still more incident rays and following out the figure on a still finer scale, a good many other rays would be found to be reflected two or more times before finally escaping from the surface. Such multiple reflection, of course, diminishes the intensity of the light just as in the multiple reflection from mirrors; for there is always a little absorption, selective or otherwise, at any reflecting surface. Thus, while the difference in the final intensities of light regularly and diffusely reflected is not so great as might be imagined, it still does exist, and for a perfectly logical reason.

To go into the matter a little further — suppose the rough surface of Fig. 13 to be not heterogeneous, but made up of a series of grooves having cross sections like saw teeth. On examining the reflection from such a surface we should find a rather remarkable state of affairs, for the course of reflection would then vary very greatly with the relation between the direction of the incident light and the surfaces of the grooves in the reflecting surface.

Light coming in one direction, i.e., so as to strike the inclined surfaces of the grooves, would get clear of the surface at the first reflection, and the intensity of the reflected beam would have a very marked maximum in one particular direction. A beam falling on the reflecting surface in the other direction, however, — that is, on the perpendicular sides of the saw-tooth grooves, — would suffer several reflections before escaping from the grooves, and hence would lose in intensity, might be changed in color, and might be considerably diffused. This sort of phenomenon one may call asymmetric reflection. As we shall presently see, it plays a somewhat important part in some very familiar phenomena.

Reflection from ordinary smooth but not polished surfaces partakes both of the nature of regular and diffuse reflection, and is, in fact, a mixture of the two phenomena, there being a general predominant direction of reflection plus a certain amount of diffuse reflection. This sort of thing is very commonly met with in practical illumination. Fig. 14, from Trotter's experiments, shows the relative reflection at various angles of incidence from common Bristol board and from the matt surface of freshly set plaster of Paris and several other materials. The specular reflection in the first-named is very strong. Such a surface gives a glaring reflection of artificial illuminants at certain angles, and the effect upon the eye is distressing. Trouble from this source is common in schools and in counting rooms, where the glare from too highly calendered paper has to be endured for long hours.

The light from artificial illuminants usually falls on painted walls, on tinted papers with surfaces more or less regular, on fabrics, and on various rough or smooth objects in the vicinity. If these surrounding surfaces are colored, — as in the case discussed a little while ago, — some curious results may be produced. Of course, light reflected from a colored surface is colored, as we have seen

already, but the manner in which it is colored is by no means obvious.

When white light falls upon a matt colored surface, the reflection is generally highly selective as regards color. Fig. 15, from Abney's data, shows clearly enough the sort of thing which occurs. It exhibits the intensity of the reflected light in each part of the spectrum when the reflecting surface is colored. The surfaces in this case were smooth layers of pigment. Curve No. 1 is the light

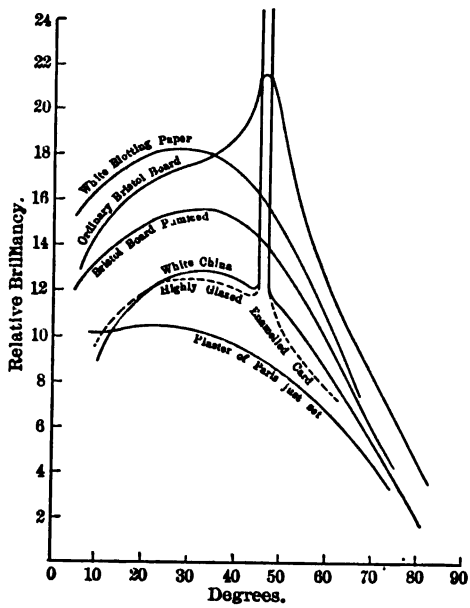


Fig. 14.

reflected from a surface painted cadmium-yellow; No. 2, Antwerp blue; No. 3, emerald green. Each curve shows a principal reflection of the color of the pigment, reaching a rather high maximum value, but falling off rapidly in parts of the spectrum other than that to which the predominant pigment color belongs. As has been already shown, pigment colors are nearly always impure, and this fact is strikingly exhibited in the shape of the curves. The color of the main body of light reflected from any one of these surfaces is plain enough.

The visible color of the light is, however, strongly influenced by the character of the surface. A shiny enamel paint, for example, will reflect specularly a good deal of light which is not strongly influenced by the pigment, but is reflected from the surface of the medium without much selective action; consequently, there will be in the reflected light both light which has taken the color of the pigment and light unchanged in color. In other words, when viewed by reflected light, the pigment color is mixed with white, and when we have a perfectly simple pigment color — such as is not found in practice — this would lead merely to lightening the tint. It may, however, have results much more far-reaching; for

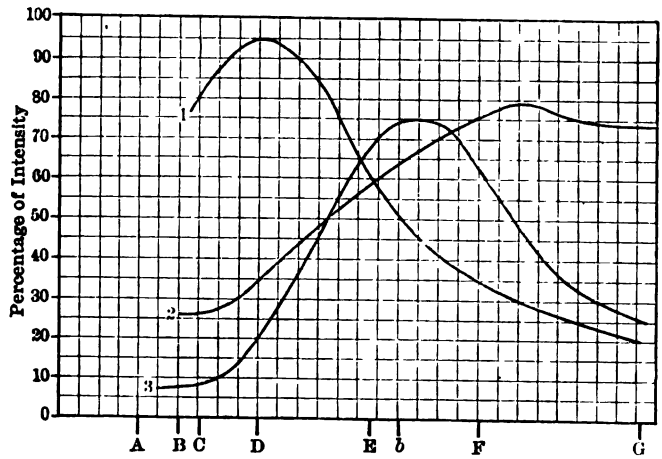


Fig. 15. — Selective Reflection.

an admixture of white light in sufficient quantity is able to shut out the distinct perception of any color, diluting it until it becomes invisible.

The effects of this dilution are most marked in the ends of the spectrum — the brighter colors at the middle being least affected by the admixture of white light; hence the fact that such a surface as we have been considering, reflecting a mixture of white and colored light, may produce a change not only in tint, but in the hue of the color, if the color, as usual, is composite. For example, a purple in enamel paint might — according to its composition — look pinkish or light blue if the surface reflection of white light were particularly strong. If the pigmented surface is not shiny

but capable of considerable reflection of colored light, another phenomenon may appear.

Fig. 16 shows curve No. 3 of Fig. 15, emerald green pigment, and below it a similar curve, resulting from a second reflection of the light selectively reflected from a pigment of that color. Assuming what is nearly in accordance with the fact, — that the second reflection follows closely the properties of the first, — the result is obviously to intensify the green of the reflected light. The clear green portion of the light reflected from this particular pigment is practically embraced between the dotted lines *P* and *Q* of Fig. 16. After one reflection the area under the curve

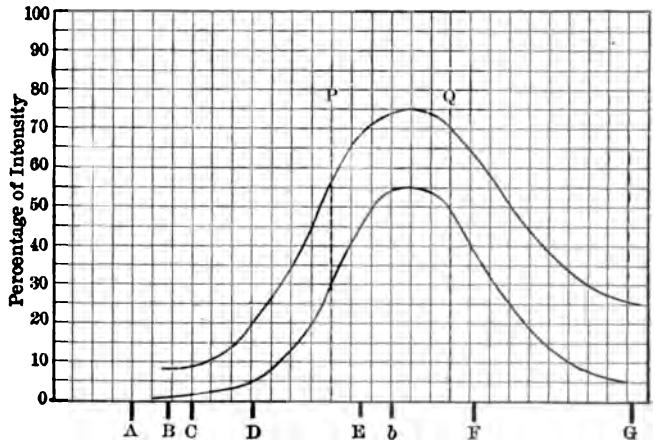


Fig. 16. — Effect of Multiple Reflection.

embraced by these two lines is about 42 per cent of the whole. After two reflections it has risen to 55 per cent, and each successive reflection — while greatly reducing the intensity of the reflected light as a whole — will leave it greener and greener.

Consequently in diffuse reflection those rays which are reflected several times before escaping from the surface are strongly colored, and the more such multiple reflections there are the more pronounced is the selective coloration due to reflection; hence, ordinary colored surfaces, from which diffuse reflection takes place, are apt to take very strongly the color of the pigment — more strongly, perhaps, than a casual inspection of the pigment would suggest.

Now, as we shall presently see, in any inclosed space the light reflected from the bounding surfaces is a very considerable portion of the whole, and, therefore, if these surfaces are colored, the general illumination is strongly colored also, whatever the illuminant may be; in other words, colored surroundings will modify the color of the illumination just as definitely as a colored shade over the source of light. In planning the general color tone of a room to be illuminated, it must be remembered that if the walls are strongly colored the dominant tone of the illumination will be that of the walls rather than that of the light.

An interesting corollary resulting from Fig. 16 sometimes appears in the colors of certain fabrics. If the surface fibers of the fabric lie in one general direction the light reflected from that fabric, which determines its visible color, follows somewhat the same laws laid down for asymmetric reflection, discussed in the case of Fig. 13.

Light falling on the fabric from the direction toward which the surface fibers run does not escape without profuse multiple reflection, and hence takes strongly the color of the pigment. Light, however, falling on the fabric reversely to the direction of the fibers undergoes much less multiple reflection, and is likely to be mixed with a large amount of white light hardly affected by pigment at all; hence, the curious phenomenon of changeable color in fabrics — for instance, a fine purple from one direction of illumination and perhaps very light pink from another.

If, in addition to the effects resulting from an admixture of white light in certain directions of incidence, one also has the curiously composite colors sometimes found in modern dyestuffs, the changeable color effects may be and often are very conspicuous; the more so, since in such colors, by multiple reflection, or — what amounts to the same thing — by more or less complete absorption of certain rays, the resultant color may be very profoundly changed.

Absorbing media sometimes show these color changes very conspicuously; as, for example, chlorophyll, the green coloring matter of leaves, which in a weak solution is green, but of which a very strong solution of considerable thickness transmits only the dark-red rays. Similar characteristics pertain to many modern dyestuffs, and result, in connection with the composite reflection

which has just been explained, in some very extraordinary and very beautiful effects.

From what has just been said about color reflection it is obvious enough that the loss in intensity in a reflected ray may be very considerable, even from a single regular reflection under quite favorable conditions. Many experiments have been made to find the absolute loss of intensity due to reflection. This absolute value of what is called the coefficient of reflection — that is to say, the ratio between the intensities of the reflected and incident light — varies very widely according to the condition of the reflecting surface. It also, in case the surfaces are not without selective reflection in respect to color, varies notably with the color of the incident light.

The following table gives a collection of approximate results derived from various sources.

Material.	Coefficient of Reflection.
Highly polished silver	.93
Mirrors silvered on back	.85
Polished gold	.80
Highly polished brass	.75
Highly polished copper	.75
Polished platinum	.63
Speculum metal	.65
Polished steel	.60
Burnished copper	.50

The losses in reflection are due to absorption and to a certain amount of diffuse reflection mixed with the regular reflection. The above figures are for light in the most intense part of the spectrum and for rather small angles of incidence. For large angles of incidence — 85 degrees and more — the intensity of the reflected beam is materially diminished, owing probably both to increase in absorption and to diffuse reflection.

Mirrors silvered with amalgam on the back, and various burnished metals sometimes used for reflectors, belong near the bottom of the table just given. Silver is decidedly the best reflecting surface; under very favorable circumstances the coefficient of reflection of this metal is in excess of 0.90. A very little tarnishing of the surface results in increased absorption and diffusion and a still further reduction of the intensity of the reflected ray. The values of these coefficients show plainly the considerable losses which may be incurred in using reflectors in connection with artificial lighting.

So far as general illumination is concerned, the light diffused at reflecting surfaces is not by any means lost, but that absorbed is totally useless. In the case of ordinary reflecting surfaces, one deals with a mixture of regular and diffuse reflection, and in practical illumination the latter is generally more important than the former, for it determines the amount of light which reaches the surface to be illuminated in ways other than direct radiation from the illuminant.

Obviously, if one were reading a book in a room completely lined with mirrors, the effect of the illumination upon the page would be vastly greater than that received directly from the source of light itself. On the other hand, a room painted black throughout would give very little assistance from reflection, and the illumination upon the page would be practically little greater than that received directly from the lamp. Between these limits falls the condition of ordinary illumination in inclosed spaces. Generally speaking, there is very material assistance from reflection at the bounding surfaces. The amount of such assistance depends directly upon the coefficient of diffuse reflection of the various surfaces concerned, varying with the color and texture of each.

As has been already indicated, diffuse reflection is rough, heterogeneous, regular reflection, more or less complicated, according to the texture of the reflecting surface, by multiple reflections in the surface before the ray finally escapes; and, therefore, the coefficients of diffuse reflection are not so widely different from those of direct reflection as might at first sight appear probable, so far at least as the total luminous effect is concerned.

In certain kinds of diffuse reflection there is considerable loss from absorption as well as from multiple reflections. This is conspicuously the case in the light reflected from fabrics, where there is not only reflection from the surface fibers, but where the rays before escaping are more than likely to have to traverse some of them. This is illustrated in a rather crude but typical way in Fig. 17, which gives a characteristic case of asymmetric reflection. We may suppose that the beam of light falls upon a surface of fabric having a well-marked nap. In the cut *aa* is the fabric surface composed of inclined fibers or bunches of fibers. These fibers, although colored, are more or less translucent and are not colored uniformly throughout their substance. Owing to their direction, rays 1, 2, and 3 get completely clear of the surface of the fabric

by a single reflection. These rays are but slightly colored, because of the comparatively feeble intensity of the coloration of the individual fibers, which have a strong tendency to reflect white light from the shiny surface.

On the other hand, rays 4, 5, and 6, inclined from the other direction, are several times reflected before clearing the surface, and in emerging therefrom have to pass through the bunches of translucent fibers that form the nap. As a result these rays are strongly colored. The amount of white light is very small and the structure of the surface has produced a marked changeable coloration.

In reality, of course, few rays actually escape on a single reflection, and those striking almost in line with the direction of the

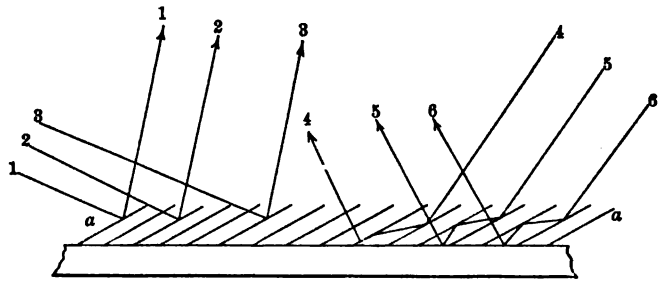


Fig. 17. — Asymmetric Reflection from a Fabric.

fibers, as 4, 5, and 6 in the figure, may be reflected many times, so that the actual effect is an exaggeration of that illustrated.

Moreover, the material of the surface fibers exercises a considerable influence on the amount and character of the selective coloration. Silk is especially well adapted to show changeable color effects, since its fibers can be made to lie more uniformly in the same direction than the fibers of any other substance, and they are themselves naturally lustrous, so as to be capable even when strongly dyed of reflecting, particularly at large angles of incidence, a very considerable proportion of white light. Being thus lustrous, they form rather good reflecting surfaces, and hence the light entangled in their meshes can undergo a good many reflections without losing so much in intensity as to dull conspicuously the resulting color effect; besides, silk takes dyes much more easily and permanently than other fibers, and hence can be made to acquire a very fine coloration.

Wool takes dye less readily, and it is not so easy to give the surface fibers a definite direction. They are, however, quite transparent and lustrous enough to give fine, rich colors. Cotton, unless "mercerized," is much inferior to both silk and wool in these particulars; hence, the phenomena we have been investigating are seldom marked in cotton fabrics.

In velvet, which is a very closely woven cut-pile fabric, the surface fibers forming the pile stand erect and very closely packed together. It is difficult, therefore, for light to undergo anything except a very complex reflection, and practically all the rays which come from the surface have penetrated into the pile and acquired a strong coloration. The white light reflected from the surface of the fibers hardly comes into play at all except at large angles of incidence, so that the result is a particularly strong, rich effect from the dyes, especially in silk velvet.

Cotton velvet, with its more opaque fibers, seems duller, and, particularly if a little worn, reflects enough light from the surface of the pile to interfere with the purity and intensity of the color. Much of the richness in color of rough colored fabrics and surfaces is due to the completeness of the multiple reflections on the dyed fibers, which produces an effect quite impossible to match with a smooth surface unless dyed with the most vivid pigments.

In practical illumination one seldom deals with fabrics to any considerable extent, but almost always with papered or painted surfaces. These are generally rather smooth, except in the case of certain wall papers which have a silky finish. Smooth papers and paint give a very considerable amount of surface reflection of white light, in spite of the pigments with which they may be colored. The diffusion from them is very regular, except for this surface sheen, and may be exceedingly strong. When light from the radiant point falls on such a surface, it produces a very wide scattering of the rays, and an object indirectly illuminated therefore receives in the aggregate a large amount of light.

A great many experiments have been tried to determine the amount of this diffuse reflection which becomes available for illumination. The general method has been to compare the light received directly from an illuminant with that received from the same illuminant by one reflection from a diffusing surface.

The following table gives an aggregation of the results obtained by several experimenters, mostly from colored papers.

Material.	Coefficient of Diffuse Reflection.
White blotting paper	.82
White cartridge paper	.80
White cardboard	.74
Ordinary foolscap	.70
Chrome-yellow paper	.62
Cream paper	.56
Light-cream paint	.52
Light-orange paper	.50
Pale-green paint	.45
Plain deal (clean)	.45
Yellow wall paper	.40
Yellow-painted wall (clean)	.40
Light-pink paper	.36
Yellow cardboard	.30
Light-blue cardboard	.25
Brown cardboard	.20
Plain deal (dirty)	.20
Yellow-painted wall (dirty)	.20
Light emerald-green paper	.18
Dark-brown paper	.13
Vermilion paper	.12
Blue-green paper	.12
Cobalt-blue paper	.12
Dark-green paper	.05
Maroon paper	.05
Black paper	.05
Deep-chocolate paper	.04
French ultramarine-blue paper	.035
Black cloth	.012
Black velvet	.004

At the head of the list stands white blotting paper, which is really a soft mass of lustrous white fibers. Its coefficient of reflection — 0.82 — is comparable with the coefficient of direct reflection from a mirror.

White cartridge paper is a good second, and partakes of the same general characteristics.

Of the colored papers only the yellows, and pink or green so light as to give a strong reflection of white light from the uncolored fibers, have coefficients of diffuse reflection of any considerable magnitude. Very light colors in general diffuse well owing to the uncolored component of the reflected light, but of those at all strongly colored only the yellows are conspicuously luminous.

Of course, all of the papers when dirty diffuse much less effectively than when clean, and the rough papers, which have the highest coefficients of diffuse reflection, are particularly likely to become dirty.

A smooth, clean, white board and white-painted surfaces generally diffuse pretty well, but lose rapidly in effectiveness as they become soiled. Greens, reds, and browns, in all their varieties, have low coefficients, and it is worth noticing that deep ultramarine blue diffuses even less effectively than black paper coated with lampblack, which has a diffusion of 0.05 as against 0.035 for the blue. Black cloth, with a surface rough compared with the black paper, diffuses very much less light; while black velvet — of which the structure is, as just explained, particularly adapted to suppress light — has a coefficient of diffusion conspicuously less than any of the others. A little dust upon its surface, however, is capable of reflecting a good deal of light.

These coefficients of diffusion have a very important bearing on the illumination of interiors. It is at once obvious that — except in the case of a white interior finish or a very pale shade of color — the illumination received by any object is not greatly strengthened by diffused light from the walls. All of the strong colors, particularly if dark, cut down diffusion to a relatively small amount, although it is very difficult to suppress diffusion with anything like completeness.

One of the standing difficulties in photometric work is to coat the walls of the photometer room with a substance so non-reflecting as not to interfere with the measurements. Even lampblack returns as diffused light one-twentieth of that thrown upon it, and painting with anything less lusterless than lampblack would increase the proportion of diffused light very considerably. Walls painted dead black, and auxiliary screens, also dead black, to cut off the diffused light still more, are the means generally taken to prevent the interference of reflected light with the accuracy of the photometric measurements.

In the case of any diffusing surface, or any reflecting surface whatever, for that matter, a second reflection has, at least approximately, the same coefficient of reflection as the first, so that for the two reflections the intensity of the beam that finally escapes is that of the incident beam multiplied by the square of the coefficient of diffusion, and so on for further reflections.

Inasmuch as in any inclosed space there is considerable cross-reflection of diffused light, the difference in the total amount of illumination due to reflection is even more variable than would be indicated by the table of coefficients given; for while the

amount of light twice diffused from white paper or paint would be very perceptible in the illumination, that twice diffused from paper of a dark color would be comparatively insignificant.

The color of the walls, therefore, plays a most important part in practical illumination, for rooms with dark or strongly colored walls require a very much more liberal use of illuminants than those with white or lightly tinted walls. The difference is great enough to be a considerable factor in the economics of the question in cases where artistic considerations are not of prime importance. The nature and amount of the effect of the bounding surfaces on illumination will be discussed in connection with the general consideration of interior lighting.

CHAPTER IV.

STANDARDS OF LIGHT AND PHOTOMETRY.

CONSIDERING the fact that the annual sum spent by civilized peoples for illuminants may be reckoned by hundreds of millions of dollars, it is somewhat extraordinary that methods of measuring light and standards by which it is to be reckoned have been, and for that matter still are, in so unsatisfactory a state. Until very recently it would be well within bounds to say that no commodity of similar total valuation has been so roughly and inaccurately measured as light.

At the present time we are beginning to reach a somewhat more satisfactory standard of precision. The fundamental difficulty with the measurement of light is that it is a physiological rather than a physical quantity and involves the uncertainties inherent in physiological measurements. One can measure out a kilowatt hour of electrical energy, or a thousand cubic feet of gas, or a gallon of kerosene, with a degree of precision good enough from the commercial standpoint; but to compute the light produced by any source through direct measurements thereof is altogether more difficult.

Until as late as 1909, at which date an informal international convention made a single unit, the international candle, standard in France, Great Britain, and the United States, each country was a law unto itself in units of light and their applications. Three questions are involved in getting a measurement of light. First, it is necessary to have a standard of reference or primary standard giving an amount of luminous energy to which the light to be measured can be referred. Second, it is necessary to have a unit of light, that is, a conventional quantity of light which may or may not be equal to the concrete thing used as a primary standard, but which represents a definite quantity in terms of which other lights are stated. Finally, it is necessary to have at least a conveniently uniform if not ideally precise procedure for the actual photometric work.

Light in the last resort is the measure of the value of the illu-

minants which one purchases, and consequently, as the aggregate amount of the purchases is very great, the importance of suitable standards and methods has long been recognized.

Historically, the oldest photometrical standard is the Carcel lamp, for many years used in France, both as a concrete standard of luminous intensity and as the unit in terms of which commercial light was to be measured. The Carcel lamp, invented just at the beginning of the nineteenth century, is an argand burner with a wick and chimney of specified dimensions, consuming colza oil, which is fed up to a uniform level at the burner by a clockwork-driven pump placed in the base of the lamp. The wick, therefore, draws from oil maintained at a constant level under practically uniform conditions. The lamp is regulated to burn 42 grams of oil per hour with a permissible variation of 4 grams on either side of the normal.

Offhand, from general experience with oil-burning argand lamps, one would say that the Carcel lamp would give but an indifferent approximation to uniformity and would be neither particularly reliable nor satisfactorily reproducible as a standard. In spite of its unpromising character, it is nevertheless true that in the hands of the French photometricians, who are used to it, it has given surprisingly good results, and it is a curious fact that the comparisons of the Carcel with the Hefner lamp used in Germany are more consistent than the comparisons between any other pair of primary standards which have been used. The Carcel gives a light of fairly good yellowish hue in amount nearly 10 candle power.

The next oldest standard used in recent times is the so-called parliamentary sperm candle legalized in 1860. This was a candle made of spermaceti, weighing 1200 grains avoirdupois, and burning at the rate of 120 grains per hour. The permissible variation in rate of burning is from 110 to 130 grains per hour, the luminous intensity being assumed to vary directly with the rate of burning. The normal diameter of the candle is 0.8 inch at the top and 0.9 inch at the base, and the wick is required to be composed of three strands, each of 18 threads.

This is the candle which is the commonest legal standard in the present statutes of this country, and was for many years the standard in England. It was and is very unsatisfactory as a primary standard, seldom manufactured so as to be close to the specifications, and remarkably subject to accidental variations. With great

care in using, it can probably be coddled to a precision of plus or minus 2 or 3 per cent, with variations twice that amount altogether too common. It is fortunately now discredited and obsolescent.

The two most important primary standards in common use are the Harcourt 10-candle-power pentane standard and the amyl acetate lamp of von Hefner-Alteneck, generally known as the "Hefner." These two standards embody the correct principle of burning a definite chemical substance easy to obtain in comparatively pure state, in lamps of dimensions so specified that they can be accurately reproduced, and under definitely specified conditions. Moreover, both have been studied for a period long enough to reveal their idiosyncrasies, and are in very wide use.

The pentane standard is employed by the London Gas Referees and the National Physical Laboratory of England as the official standard, and is being considerably employed by American gas companies. The Hefner lamp is in universal use as a standard throughout Germany and German speaking countries, and to a very considerable extent elsewhere.

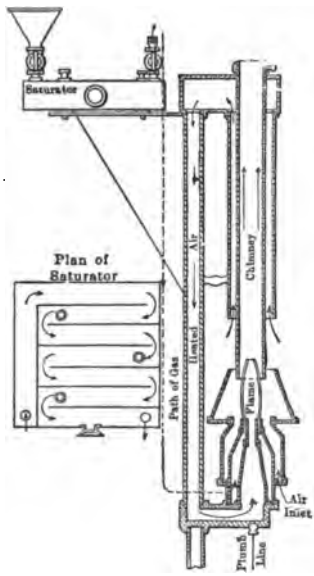


Fig. 18.

The pentane standard is essentially an argand gas burner fed by air saturated by pentane vapor. The lamp and some of its parts are shown in section in Fig. 18. The carburetor is a rectangular box containing baffle plates, around which the air has to pass to become saturated in going down to the burner.

The burner itself is of the argand form with a steatite ring containing the outlets, and is surmounted at a height of 47 millimeters by a brass chimney surrounded by an annular space, passing through which the air supplied to the burner is preheated. The flame is without a surrounding chimney, but is protected by a conical shield cut away to allow the flame to be visible. The normal height of the flame is $2\frac{7}{8}$ inches.

The apparatus is obviously somewhat intricate, but when carefully handled under closely regulated conditions gives a rather

satisfactory degree of precision. It is probably good within one per cent on either side of the normal when carefully used, and duly corrected for barometric pressure, humidity, and CO_2 in the air. A strong point in favor of the pentane standard is the considerable light it gives, substantially 10 candle power, and the fact that the flame is fairly white. Some care has to be taken to

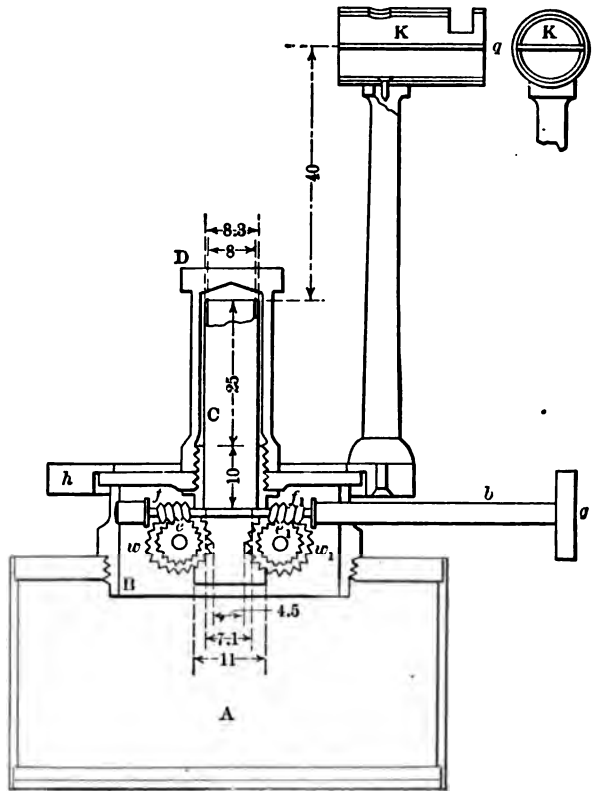


Fig. 19.

secure pentane of adequate purity, as, while it is a definite chemical compound which can be obtained absolutely pure, the common source of the pentane used is such as to render probable its contamination with small amounts of other hydrocarbons which may vary the illuminating power of the gas.

The Hefner lamp is simpler and more easily reproducible than the pentane standard. It is shown in section in Fig. 19, in which

the essential dimensions in millimeters are given. Here A is the body of the lamp, closed by the cap B which carries the working parts. These are essentially the wick tube C and the wick-adjusting mechanism which consists of two worms f, f_1, meshing into gears e, e_1, which carry the wick wheels w, w_1.

A rotating cap h carries a pillar upon which is mounted the optical flame gauge K, which is merely a sighting apparatus by which the flame can be adjusted to exactly the required height. The wick tube carries a snugly fitting, woven cotton wick, adjusted to the top of the wick tube by a cap gauge furnished for the purpose. The standard height of the flame is just 40 millimeters. The fuel is pure amyl acetate. The wick chars very little while the lamp is in use, but it should be kept evenly trimmed.

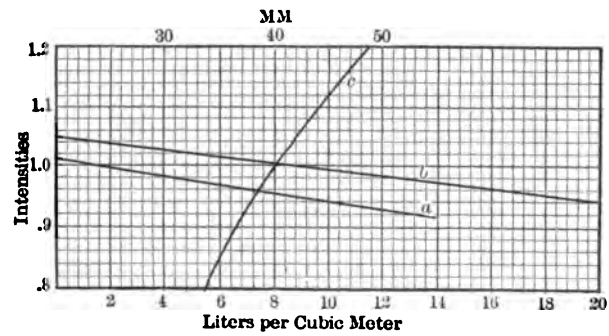


Fig. 20.

The intensity of the light varies with the flame height, the barometric pressure, and with the moisture and CO_2 present in the air. The corrections due to these several causes have been carefully worked out and are shown graphically in Fig. 20. In this the ordinates are proportional intensities. Curve a exhibits the variation of intensity with the proportion of CO_2 in the air. Curve b is the variation of intensity with humidity. Curve c, read by the upper scale of abscissæ, gives the variation with the flame height in millimeters. The barometric correction is very small, the intensity varying about 0.01 per cent per millimeter decrease of pressure, the normal being 760 millimeters.

The lamp should be used in a well-ventilated room free from draughts, as the small flame is somewhat sensitive, and should be allowed to burn about half an hour before beginning meas-

urements. The light given by the Hefner lamp as described is 0.9 of an international candle; at a flame height of 45 millimeters, other things remaining the same, the lamp gives just one international candle.

The chief objections to the Hefner are its small luminous intensity and the strong reddish color of the flame, which introduces into comparisons made with it the difficulties of color photometry to a somewhat undesirable degree. When carefully handled, it, like the pentane standard, is probably accurate to about one per cent, although in the case of both these lamps variations of double this amount in case of different lamps operated by different people should not create surprise.

The only other primary standard of light of any importance is Violle's platinum standard, thus far of very little importance as a concrete standard of reference, but of great significance as being indirectly the basis of the international candle. In 1881 at the Paris Congress, Violle proposed, as a standard of light, that radiated from a square centimeter of melted platinum at its point of solidification.

In its original form the scheme of operations required not less than one kilogram of molten platinum re-fused for each new observation, and the apparatus was very troublesome to work with. Later modifications of the apparatus by Siemens, Petavel, and others have proved somewhat easier to operate, but the consensus of opinion is that as a primary standard it is more troublesome and less precise than either the Hefner form or the pentane lamp.

Nevertheless the Violle standard was adopted by the Paris Electrical Congress of 1881, and the twentieth part of this unit, determined in practice by comparison with the Carcel lamp, has been considerably used in France under the name of the *bougie decimale*, which in turn has been adopted as the present international candle.

The international candle, therefore, is not a primary standard at all, but a unit of luminous value derived from intercomparison of the Carcel, Hefner, and pentane primary standards. By 1907 it had become evident that there were outstanding differences between the relative values of the units of light commonly received, sufficient to demand commercial attention. The initiative in the matter was taken by the Illuminating Engineering Society, which appointed a committee on units and standards including

distinguished foreign members of the society in France, England, and Germany, and charged it with the work of undertaking to obtain an international convention on a working unit of light.

The work was actively taken up, in coöperation with the society, by the American Institute of Electrical Engineers, the American Gas Institute, and the National Laboratories of France, England, and the United States.

As the result of elaborate intercomparisons between the primary standards of light in use, both directly and via incandescent lamp standards, at the three laboratories mentioned and at the Reichanstalt, it was finally determined that the unit of light should be taken at the value of the *bougie decimale*, of which the Hefner standard should be taken as nine-tenths.

The necessary concessions were made by the bodies interested to bring the values of commercial standards into harmony with this determination, and since June 1, 1909, this international candle has been the standard in France and in English-speaking countries, and is gradually winning adherence among other nations. The German practice still retains the Hefner as unit as well as primary standard, since its difference from the international candle is so considerable as to cause more or less commercial inconvenience. The incandescent lamp has been taken as the custodian of this unit value, since intercomparisons of incandescent lamps can be made with a relatively very high degree of precision; yet it must be remembered that flame standards, whether primary or secondary, have a direct and great value in determining the value of commercial flame illuminants, inasmuch as by the use of flame standards the corrections for moisture, CO_2, and barometric pressure become either negligible or so small as to be very readily made, while comparisons between flames and incandescent lamps involve all these corrections at their full values. The relations between the intensities of the various primary standards and the international candle unit are given in the following table:

RELATIONS BETWEEN PRIMARY STANDARDS.

Standard.	International Candle.	Carcel.	Hefner.	Old English Candle.
International candle	1.	0.104	1.11	0.98
Carcel lamp	9.6	1.	10.7	9.4
Hefner	0.90	0.0935	1.	0.88
Old English candle	1.02	0.106	1.14	1.

The secondary standard most in use, as just stated, is the incandescent electric lamp. After a lamp has been aged by burning about 200 hours its candle power falls off only very gradually with further use for about an equal period, so that if a lamp standardized after aging is used only for calibrating a working standard it remains reliable far within the errors of observation for a considerable period. Practical standards of a high degree of precision are therefore readily available in the form of incandescent lamps.

As a secondary flame standard the Methven screen has been considerably used, particularly in England. This standard is a powerful argand gas burner fitted with a chimney and having adjusted in front of it 1½ inches from the axis of the flame a blackened metal plate having a slot just in front of the flame 1 inch high by 0.233 inch in width. A section of flame thus cut out is a very convenient and steady secondary standard of about 2 candle power. In this country the Elliot lamp has proved a valuable adjunct in gas testing. It is a kerosene lamp, of the "student lamp" type, of which a definite area of the flame is exposed by a slot, as in the Methven screen. The section of the flat flame thus cut out remains sensibly uniform in light for a considerable period. These secondary standards and the 10-c.p. pentane primary standard are now rapidly displacing the discredited "standard" candle for gas testing, so that for all illuminants there is now a definite basis of reference to the international candle and to the Hefner, which is a determinate fraction thereof.

Granted a unit of light intensity such as is furnished by the international candle, and a concrete standard representing it or a known multiple thereof, the fundamental process of light measuring is the determination of the intensity of some working source of light in terms of the unit.

Photometry is the art of comparing light intensities, and as such it is the basis of the quantitative part of illuminating engineering. In the last resort, a photometric comparison depends upon the ability of the eye to detect small differences in luminosity, and the photometer ordinarily is an instrument designed to present to the eye two similar juxtaposed surfaces, one lighted by the source of known intensity and the other by the source of unknown intensity, together with means of varying either or both of these intensities in a determinate manner.

The power of the eye to recognize the minute differences of luminosity necessary to precise photometric measurement depends on the value of Fechner's fraction, to which reference has been made, and the fine art of photometer design is to so arrange the apparatus as to aid the shade perception of the eye in the most efficient possible manner.

The earliest form of photometer, that of Bouguer, now more than a century and a half old, is absolutely typical of photometric principles. In diagram it is shown in Fig. 21. Here *ab* is a screen with an opaque partition *cd* perpendicular to its middle point *c*. This screen may be a diffusing surface like cardboard, or a translucent material like thin paper or milky glass. In the first case it is viewed from the front, in the latter from the rear; *L* and *L'* are the lights to be compared, the former illuminating the screen over *ac*, and the latter over *bc*. When one of the lights is moved to or from the screen until the two halves of the screen are of equal apparent brightness, then the intensities of the lights are proportional to the squares of their respective distances, *d* and *d'*, from the screen. Obviously the dimensions of the screen should be small compared with *d* or *d'*, so that the illumination may be sensibly uniform over each half; and these must be equal in reflecting or transmitting quality, so as to introduce no constant error due to dissimilarity of the two halves. Two areas thus merely juxtaposed with a black line of demarcation between them do not present the most favorable conditions for delicate shade perception, and the betterment of these conditions has been the object of such improvements as have been made in the photometer.

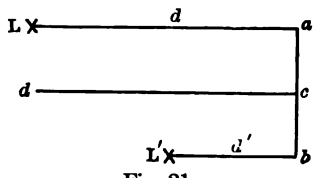


Fig. 21.

Of practical forms of photometer there are many, differing chiefly in the nature and arrangement of the luminous areas to be compared and in various details of convenience. The only radical departure from Bouguer's principles is in the case of the so-called flicker photometers, to be described presently.

The two typical forms of photometer in most general use are the Bunsen and the Lummer-Brodhun, so called for the respective inventors of the comparison screens. The Bunsen photometer consists essentially of a graduated bar, with one of the lights to

be compared at each end, merely for the purpose of enabling the distances of the two lights from the observing screen to be easily determined. On the bar slides a sight box containing the Bunsen screen and carrying a pointer moving over the scale. The general disposition of the parts is shown in Fig. 22.

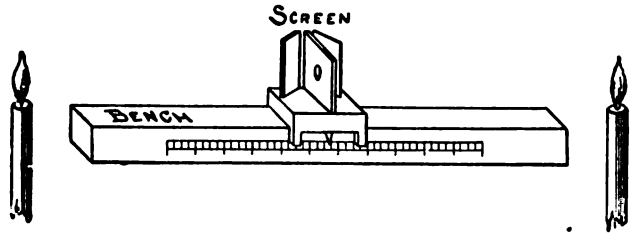


Fig. 22.

The length of the graduated bar is commonly 100 inches if graduated in English measure, 2.5 or 3 meters when in metric measure. The sight box as commonly made is shown in plan in Fig. 23. The Bunsen screen forms the middle partition shown in the box, upon which the light from the sources on either side falls. Two mirrors, m_1 and m_2, placed substantially as shown,

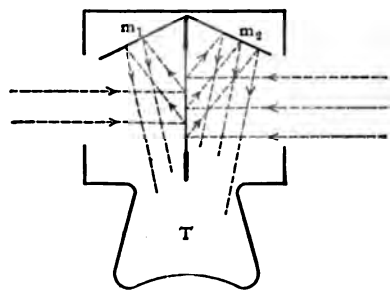


Fig. 23.

enable one looking into the wide sight tube T to see both sides of the screen at once.

The Bunsen screen itself in its commonest form consists of a disk of opaque, matt-surfaced white paper with a sharply defined central spot made translucent by grease, usually paraffin. As already explained, such a spot appears bright or dark on the general surface of the disk according as the illumination behind it is stronger or weaker than that on the front. With a screen in perfect condition

the spot will nearly or quite disappear when the illuminations are equal. When the screen is so placed on the photometer bar that this condition is fulfilled, the intensities of the lights to be compared are respectively as the squares of their distances from the screen, this being the condition for equality of illumination, or in the more general case this same condition holds when there is equal contrast between spot and surface as seen in the two mirrors.

To eliminate inequalities of appearance due to difference between the two sides of the screen or between the two mirrors, the sight box is commonly made rotatable through an angle of 180 degrees, so as to reverse the position of the screen and mirrors with respect to the two lights under comparison. These two lights

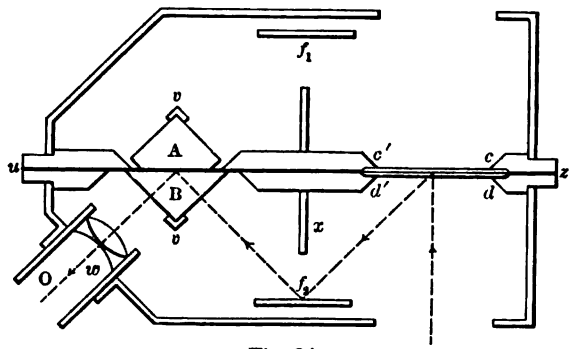


Fig. 24.

must be screened off from the observer so that they will not interfere with his judgment, and black screens with large central holes are commonly mounted on the bar so as to intercept stray light; and for the same reason it is desirable to operate in a darkened room with black walls. If the intercepting screens do their work very completely, the black wall surface is not absolutely necessary, but it is on the whole to be preferred.

A very material improvement over the Bunsen grease-spot disk is the Leeson disk, which consists of a piece of thin white translucent paper sandwiched between two pieces of opaque white paper with central star-shaped openings, so that the disk presents a sharply defined star, preferably with 10 or 12 narrow points, the whole being 1 inch to 2 inches in diameter. This Leeson disk is worked precisely like the Bunsen disk, but since its outlines are usually sharper the Leeson disk gives rather more precise settings.

It is desirable, for accurate estimate either of equality of brightness or of contrast, that there should be no debatable ground between the two areas compared; that is, that the two should come sharply up to each other without a perceptible dark line between them. This condition is fulfilled more perfectly by the Lummer-Brodhun screen than by any other device yet contrived, and for precise laboratory work this is the screen usually adopted, the mounting of the other parts of the photometer being practically as in the Bunsen. The Lummer-Brodhun sight box complete is shown in plan in Fig. 24. The box is mounted on the photometer bar so as to be rotatable through 180 degrees, with its axis of rotation, *uz*, perpendicular to the bar. The screen proper, *c,c'*, *d,d'*, is

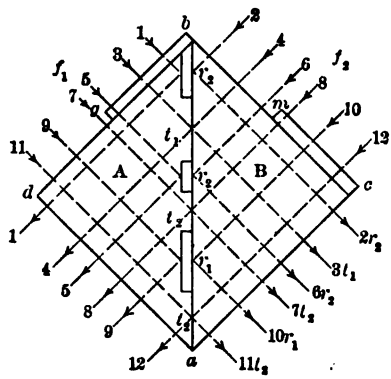


Fig. 25.

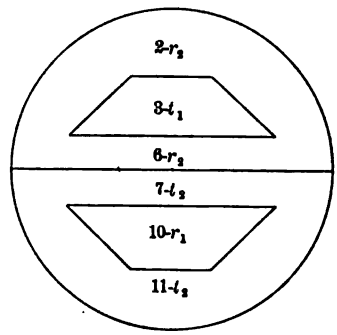


Fig. 26.

a disk, usually of compressed magnesia, which gives a very perfect matt surface, upon the two sides of which fall normally the rays from the lights under comparison. This screen is viewed simultaneously from both sides by means of the mirrors f_1, f_2, and the right-angled prisms, *A,B*. A cross screen, *x*, serves to cut off scattered light.

The prisms with the paths of the rays through them are shown in Fig. 25. The hypotenuse faces of the prisms are ground optically flat and clamped together. But, prior to clamping, the surface of *A* is recessed by sandblasting in vertical strips, r_1, r_2. When the prisms are clamped into optical contact, light falling on the hypotenuse surface of *B* opposite these recesses is totally reflected, while in the intervening spaces, t_1, t_2, it is transmitted. The path of the rays is plainly shown by the dotted lines, and the result is

that the odd-numbered rays received from c,c' via f_1 enter the sight field only through the contact faces t_1,t_2, while the even-numbered rays from d,d' via f_2 enter only by total reflection at r_1,r_2.

The result is a sight field that looks like Fig. 26, each half-circle receiving light from one side of the screen and having superimposed upon it a trapezoidal area received from the other side of the screen. The sight box can be set for disappearance of these areas so as to present a uniform field, or by inserting two slips of glass *mc*, *gb*, Fig. 25, the trapezoidal areas can be slightly darkened so that when everything is in balance one sees two shaded areas in a uniform field and thus works by equality of contrast. The field is viewed by a magnifying lens *w*, Fig. 24, set in a sliding eye-tube, *O*.

This arrangement of sight field is wonderfully sensitive in showing small variations of intensity, certainly a good deal more sensitive than the Bunsen or Leeson disks, especially when the lights compared are of similar color. Opinions differ among photometrists as to their relative sensitiveness, but the general result of experience seems to be that while the mean error of a single setting with the Bunsen or Leeson disk is likely to be nearly 1 per cent, that obtained with the Lummer-Brodhun screen worked for contrast will be less than one-half per cent, and under favorable circumstances down to one-third or one-fourth per cent. Most operators prefer the Bunsen or Leeson disk for lights differing materially in color, as, for example, in the comparison of a carbon-filament incandescent lamp with a tungsten lamp or with incandescent gas. Under such circumstances photometric settings are likely to show nearly double the mean errors just referred to, the Lummer-Brodhun suffering relatively somewhat more than the others.

The difficulty of forming a just estimate of equality of brightness or of contrast in the case of two illuminations differing in color is so great as to constitute the largest outstanding source of error in photometry. It is not putting the case too strongly to say that there is no simple method of comparing lights differing much in color with a reasonable degree of precision. Various subterfuges have been adopted for such comparisons, which are convenient rather than satisfactory. Perhaps the best of them is the use of the so-called "flicker" photometer.

The essential point of this instrument is the rapid exchange of the two illuminations to be measured with respect to the sides

of the viewing screen, and the principle may be by one arrangement or another applied to almost any kind of screen. One of the best known and simplest forms of flicker photometer is the Simmance-Abady.

The essential part of this device is a disk of plaster of Paris, say five-eighths inch thick and $2\frac{1}{2}$ inches in diameter, rotating on an axis parallel to the photometer bar. The disk is molded so as to form a species of double conoid, which, when looked at edgewise, presents a surface illuminated by the two sources in turn, the transition from one reflecting position to the other being gradually accomplished by the rotation of the disk. Fig. 27 shows three edgewise views of the disk, which, when looked at from above as indicated, gives an inclined surface to the right, a wedge reflecting from left and right, and an inclined surface to the left in succession as the disk turns. The disk is mounted in a box, with apertures on the sides to admit light, a viewing telescope, and a spring or other motor for rotation with means for regulating the speed.

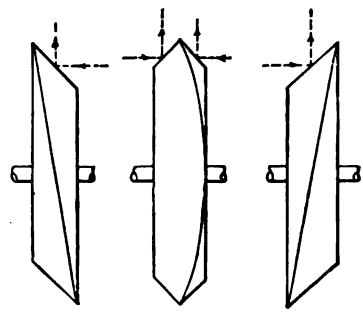


Fig. 27.

Obviously, if one of the lights is noticeably brighter than the other and the disk is turning at a moderate rate of speed, a strong flickering sensation will be produced, which disappears when the illumination on the two sides of the disk becomes equal. In the comparison of colored lights the blending of the two colors by the rotation of the disk diminishes very considerably the troublesome contrast presented by two juxtaposed colored fields, the colors being, as it were, optically averaged and the screen being then adjusted until the flicker disappears.

The flicker instruments generally give, in the comparison of two lights differing considerably in color, as, for example, a very low efficiency carbon incandescent and a tungsten incandescent, results differing by several per cent from those obtained from the same lights compared by ordinary photometer screens. In the case of lights varying still more in color, the difference may rise to 10 or even 20 per cent. The weight of the evidence indicates that the

flicker principle is of much value in comparing lights of different colors, since the readings obtained by a number of observers on the same pair of lights generally show for smaller differences with the flicker photometer than with the ordinary form.

Yet even this consistency is not wholly satisfactory evidence of precision. Generally speaking, the flicker instruments do not allow of as quick and easy balance as those with fixed screens, although the precision of the balance when obtained is much better than seems probable while it is being made. Very high precision is claimed for some of these instruments, particularly by their inventors, but most photometrists hardly expect to obtain with them any smaller average deviations than with the ordinary grease spot. Flicker instruments work badly in weak illumination.

Two other schemes for avoiding the color difference in the comparison of lights are worth noticing here. One of them is the use of standard color screens, the coefficient of absorption of which can be obtained by the spectrophotometer and which serves to reduce the two lights under comparison to approximately the same color. The other is the preparation of a set of secondary standards presenting only slight successive differences of color and yet on the whole reaching a wide difference. This divides the color-matching difficulty into steps, as it were, which renders photometric settings much easier. Both these methods are somewhat roundabout and, like the flicker photometer, lessen rather than abolish the color difficulty. Probably any one of them yields results sufficiently good for most commercial purposes, but where scientific precision is required all leave much to be desired.

For a full discussion of the problem of heterochromatic photometry the reader is advised to consult the various treatises and papers dealing specifically with this matter, which will be found interesting and instructive, although not always convincing. Photometry is at best a process involving physiological and psychological quantities of a somewhat indeterminate character. Even with the same instrument and comparing lights of similar magnitude and color, different observers are likely to find slightly different ratios, and the same is true if one considers even the observations of the same observer on different days. These differences may amount to a considerable fraction of a per cent, plus or minus.

The fundamental thing in photometry is to make the best use of the instrument at hand, to hold the lights under comparison abso-

lutely steady, and to eliminate as far as possible constant errors due to the apparatus. In the comparison of flames, this implies very careful sheltering from draughts and close attention to the conditions of the air and of the standard flames. In comparing incandescent lamps with each other, the utmost care must be taken to hold the voltages uniform during the comparisons. It is best to put the lamps upon the same circuit, preferably supplied by a storage battery or by a special generator, and to arrange the connections somewhat as shown in Fig. 28. The lamp sockets *A* and *B* should be connected at opposite ends of the photometer bar by heavy copper leads, to which can be joined, by closing a switch, the circuit terminals, *a* and *d*. In circuit with *a* or *d* should be a resistance of large capacity, *R*, for approximate adjustment of the voltage. *R* should be able to carry the maximum current likely to be needed without sensible change of resistance, and should be either in very numerous steps or continuously adjustable like a water rheostat. Each lamp socket, *A*, *B* (Fig. 28), should also be in series with its own adjusting rheostat, *r*,*r'*. These rheostats should have a capacity sufficient to give a range of say 10 to 20 volts at the lamps, and the less their temperature variations and the finer their gradations the better. The voltmeter, *E*, should be a double-scale instrument of extra-high resistance, with fine graduations, and preferably with illuminated scale. A high scale to 250 volts and a low scale to 25 volts is a convenient arrangement.

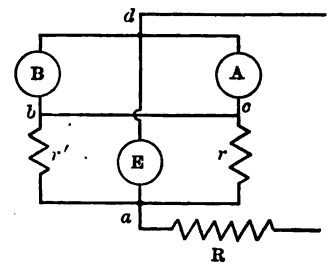


Fig. 28.

Switches should be provided to make the following voltmeter connections: (1), *b* to *c* on low scale; (2), *a* to *d* on high scale; (3), *b* to *d* on high scale; (4), *c* to *d* on high scale. Position 1 is the differential connection used in holding the lamps at voltage; the others are for the approximate adjustments. In comparing lamps of very different voltage, it is convenient to connect *bc* through the high scale. A reversing switch should be in *bc* unless the voltmeter scale reads both ways. Ammeters or wattmeters when used should be connected between *b* and *B*, or *c* and *A*, so as to get inside the voltmeter, the current capacity of which ceases to be negligible when one tests lamps of small candle power or very

high efficiency. All rheostat handles and switches should be within easy reach of the observer at the voltmeter.

The method of working which should be employed whenever it is possible is that of substitution. At one end of the photometer bar, as at A, should be placed a properly aged lamp to be used as a working standard. The primary or tested standard is generally at B and its relation to A is determined without reversal of the photometer screen. Then without any changes in the apparatus B should be replaced in succession by the lamps to be tested and photometric balance secured. By this means any want of sym-

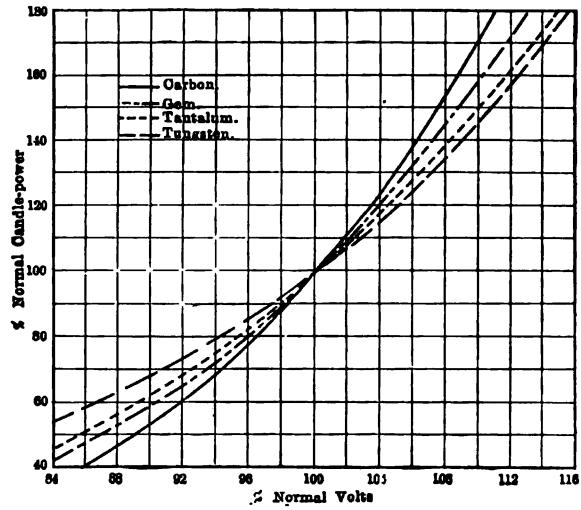


Fig. 29.

metry in the screen or in the photometric apparatus generally is eliminated, since the ratios of B to A, and of the unknown lamps to A, are determined under exactly the same conditions. The one important matter during the test is to hold the voltage constant, for while the lamps may be rigorously held at the proper difference of voltage it does not follow that the light ratios will be the same when the absolute voltages vary, since different lamps gain or lose light to different extents with change of voltage, and consequently if the voltage on the testing circuit varies an error may be introduced. The nature of this error is shown in Fig. 29, which displays variations in candle power produced by change of voltage

on ordinary carbon, G.E.M., tantalum, and tungsten lamps. It will readily be seen that a variation in the general voltage of even a half a volt is sufficient to produce measurable errors even when the lamps are held rigorously at the required difference of voltage for which they are supposed to be normal. It is easy to hold the circuit voltage close enough for comparison of different carbon lamps or of different metallic filament lamps, but in comparing a carbon with a metallic filament lamp far greater care is necessary. It is advisable, therefore, to have working standards of both kinds. In comparing electric with other lamps, it is obvious that the voltage control must be of the most exact kind in order to avoid material errors.

In the simplest form of comparison between two lights the comparison is made in a single azimuth only. Standard lamps have commonly a certain marked direction for which they are standardized, and to this direction they must be exactly oriented. It has been rather common practice, inasmuch as incandescent lamps are often rated by their mean horizontal candle power, to rotate the lamps during measurements, and indeed some standards are made for use during rotation. To this end a socket capable of revolution by a motor at three or four times a second is often provided at one end of the photometer bar, as at *B*, and in this the standards and the lamps to be tested are to be used; the working standard at *A*, being merely a light of constant value, remains at rest.

In using these rotating sockets considerable care has to be exercised to prevent any variable drop in voltage at the contacts, and the tendency at present is to use the rotator less and less. Most modern incandescents, especially metallic filament lamps, give a nearly uniform horizontal distribution, and metallic filament lamps in particular can not be rapidly rotated without risk of distorting the filament. Except in lamps with very peculiarly placed filaments, three measurements taken 120 degrees apart around the vertical axis will give the mean horizontal intensity within the limits of ordinary commercial accuracy.

There are many devices for measuring the mean horizontal or the mean spherical intensities of light sources, most of them rather intricate and troublesome. Descriptions of these methods may be found in modern treatises on photometry, but elaborate explanation of them is out of place here. The one most satisfactory and

convenient method of getting the mean spherical candle power, which is, in modern practice, the only suitable method of comparing illuminants, is found in the sphere photometer commonly known as the Ulbricht sphere. The fundamental principle of this is that if a luminous source be placed at the center of a hollow sphere, the inner surface of which is a good diffuse reflector, the illumination at a peephole in the sphere shielded from direct rays received from the source is directly proportional to the mean spherical intensity of the source. A good account of the theory of this sphere is given by Dr. Bloch in the *Elektrotechnische Zeitschrift* of Jan. 18, 1906, page 63. The sphere itself is commonly made of heavy sheet metal, made up in two hemispheres separable by handles, or in large spheres by fitting them on a sliding track. The diameter depends on the purposes for which the photometer is intended; if for incandescent lamps, a meter is sufficient, while for arc lamps it should be not less than two meters.

The interior of the sphere is usually painted dead white with a barium-sulphate paint. The light at the peephole may be balanced by any suitable photometer screen against a standard lamp, and the whole affair is calibrated by suspending in the sphere an incandescent lamp of which the mean spherical candle power has already been determined by the point-to-point method, that is, by measuring the intensity in a considerable number of directions uniformly spaced on the surface of an imaginary sphere surrounding the lamp. A description of this point-to-point method may be found in the *Journal of the Franklin Institute*, September, 1885, Supplement; and a valuable paper on the precautions to be taken in using the integrating sphere, by Sharp and Millar, is to be found in the Transactions of the Illuminating Engineering Society, Vol. III, page 502. For the testing of arc lamps, always a difficult matter, the use of the integrating sphere is almost a necessity, the only effective substitute for it being the integrating photometer of Matthews, which, though giving satisfactory precision, is far more intricate. A description of this apparatus, important on account of the numerous and valuable measurements secured through its use, will be found in Transactions of the American Institute of Electrical Engineers, Vol. XX, page 69.

From the standpoint of the illuminating engineer the most interesting photometers are those intended for portable use, by which one is enabled to measure intensity of light sources *in situ*,

and the illumination received from them. The problems of measuring the intensity of a light and the illumination produced by it on a surface are virtually the same, since in either case the process of photometry is the balancing against a surface illuminated by a known light another surface illuminated by the unknown light, and it makes no difference whether this second surface of the photometer screen receives its light from a lamp directly or from a surface illuminated by that lamp. The only essential difference is that the illumination photometer is calibrated with reference to the secondary source of illumination which is to be employed with it, that is, with respect to the surface either diffusely reflecting or diffusely transmitting light from the source under investigation.

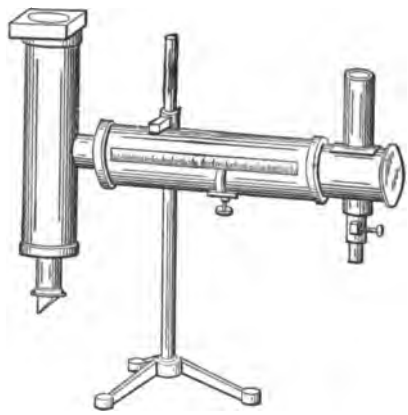


Fig. 30.

A photometer for portable use is, however, a much more troublesome affair than one set up in the laboratory. The same photometer screens can be and are used in each, but the difficulty is in providing a reliable standard light and suitable means for modifying its intensity to secure a balance against the light to be measured without being driven into inconvenient complications or apparatus too bulky to be portable. The type of portable photometers is that of Dr. L. Weber. A general view of one of the forms of this instrument is shown in Fig. 30, and a diagrammatic section of it in Fig. 31. The instrument is composed of two main tubes, *A*, *B*, connected by a collar *C*, permitting one

tube to rotate with respect to the other. *A* carries at its outer end a lamp case *G*, containing the standard light: in the earlier instruments a small benzine lamp, as shown in Fig. 30, in recent instruments more often an incandescent lamp operated from a storage battery. A screen of translucent glass, *F*, is fitted to slide back and forth along the tube *A*, being moved by the handle *a*, which carries a pointer over a scale on the side of the tube. The end of the other tube, *B*, is closed by a screen, *G'*, also of diffusing translucent glass. At *D* is a Lummer-Brodhun prism viewed by the eyepiece *E*, usually provided with a right-angle prism to make observation convenient when the tube is in a vertical position.

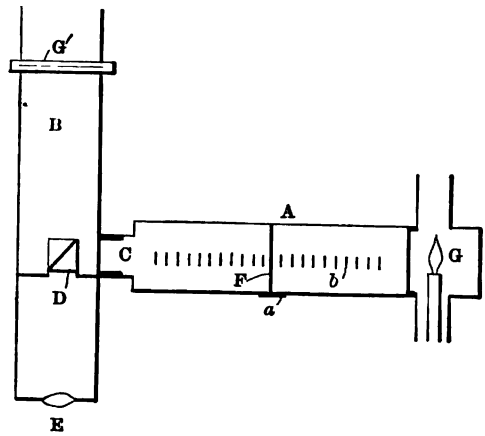


Fig. 31.

In use, the sight tube *B* is pointed at the source to be measured, with the screen *G'* in place, and a balance is then effected by moving *F*. Knowing, then, the distance, l_1, of the source, I_1, examined, and the intensity, I, and distance, l, of the standard,

$$I_1 = \frac{l_1^2}{l^2} I;$$

assuming the two diffusing screens to be exactly similar, or generally

$$I_1 = K \frac{l_1^2}{l^2} I,$$

wherein K is the ascertained ratio of the screens. Several diffusing screens are supplied with the instrument to increase its work-

ing range, also a diffusing screen to act as a secondary source of illumination by reflection, G' being in this case removed. In practice it is found that the law of squares holds only very roughly for the positions of the movable screen F, so that for careful work the scale must be calibrated by experimental settings on lights of known intensity and distance. When such calibration is properly made in the laboratory, the instrument is capable of excellent work. When used for determining illuminations directly, the tube is left vertical and the light falls on the diffusing screen G', or, this screen being removed, the sight tube is pointed at a white diffusing surface set at an angle with it.

When properly calibrated for known illuminations falling on either of these screens, the Weber photometer works well for illumination measurements. In using it in this way the condition of the diffusing surfaces requires very close attention, and the calibration of this or any other instrument for a similar purpose requires to be very carefully watched, for it cannot be predetermined from the dimensions of the instrument and is subject to change without notice from the effects of dirt.

A considerable number of portable photometers based on the general scheme of the Weber instrument have been devised and are in successful use. They differ chiefly in the means taken to vary the standard light in securing a balance. A fixed diffusing screen, the area of which is cut down by a cat's-eye; moving the lamp itself, varying the current or voltage applied to the lamp, are some of the methods employed, each of them in several different instruments. They are all effective provided close watch is kept on the calibration of the instrument, and not otherwise. The principal differences between these modified Weber photometers are differences of detail bearing on convenience of manipulation, which in most cases leaves much to be desired.

As a class most portable photometers are only moderately portable; very few of them can be operated without the coöperation of two or more observers. Yet in skillful hands with proper calibration they all are capable of giving fairly good precision,—good enough at least for the conditions of their use. It must not be forgotten that portable photometers are not used to measure lights operated as they would be in the laboratory. On the contrary, they are commonly employed for the photometry of arc lights, the intensity of which is subject to accidental and

periodical variations of 10 to 50 per cent; or for measuring incandescent electric or gas street lights; the voltage and current being only approximately known in the former case and the pressure in the latter being very uncertain.

When used for illumination measurements they are usually evaluating the effect of lamps, operated at unknown voltage or gas pressure and in unknown stages of deterioration, in lighting interiors in which the conditions of wall reflection are unknown and subject to variations, and where the fittings cause local changes in illumination many times greater than the largest possible error of photometric balance. For work in the laboratory the portable photometers of the better class are capable of as good precision as fixed photometers, and the usual increase in the errors of measurement is due to the conditions of use rather than to intrinsic faults in the instruments.

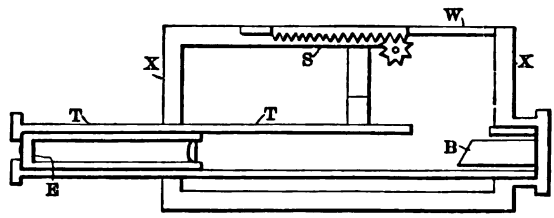


Fig. 32.

A few instruments of a totally different class are in use for the estimation of illumination. These are photometers based on visual acuity; in other words, instruments depending upon the capacity of the eye for reading type in a dim light. One familiar type is the illuminometer of Houston and Kennelly. It is essentially an extinction photometer, the light received from the source under examination being varied until certain test characters cease to be visible. This illuminometer is shown in section in Fig. 32. Here *X*,*X* is a blackened box fitted with an observing tube *T*, in which an eyepiece *E* can be slid to focus upon the test plate *B*. At *B* are the test characters, letters and figures bearing no relation to each other, and these are illuminated through the window *W*, of translucent material. This window can be varied in aperture by the shutter *S*, moved by a rack and pinion from the outside, where an arbitrary scale is provided. The window *W* is turned to the light to be examined and the shutter is then moved until the test

characters are just visible, when the illumination can be read off upon the previously calibrated scale.

Another instrument of similar character is the reading photometer shown in section in Fig. 33. This instrument is a blackened box mounted on a convenient handle and fitted with a wide eye hood S and a short sight tube L on the rear side of the box; at C is a card bearing unrelated letters or characters. A variety of cards with various characters is provided to increase the range of the instrument and to prevent the observer from becoming acquainted with the characters. In use, the hood S is held to the eyes while the sight tube is pointed over the shoulder toward the light to be observed, and the observer then walks away until he

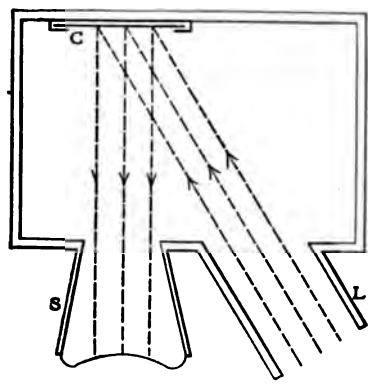


Fig. 33.

is unable longer to read the characters upon the card. The vanishing value of illumination for each card has to be determined as well as may be by a previous calibration, unless, as is more usual, the instrument is used for merely comparative purposes.

As commonly worked, with cards and type so coarse as to be dimly legible under an illumination of only a few thousandths of a foot-candle, this reading photometer is subject to so enormous a personal equation as to be utterly unreliable, although if used by a single person thoroughly familiar with it and with considerably finer type than that customarily supplied, it is not wholly to be despised as an adjunct to the judgment. The type used in an instrument of this class should be at least as fine as ordinary newspaper type to avoid bringing the extinction value of the illumination so low as

to compel the eye to work under conditions that make the result depend almost entirely on the state of adaptation of the eye and the imagination of the observer.

The same criticisms hold to a somewhat less extent for the illuminometer previously described and for all other instruments that depend on reading characters under greatly reduced illumination. Such instruments when carefully used within moderate range of intensities are sometimes very convenient and reasonably consistent, but the personal equation involved in their use is too large and too variable to render them generally trustworthy.

CHAPTER V.

THE MATERIALS OF ILLUMINATION — ILLUMINANTS OF COMBUSTION.

At root, nearly all practical illuminants are composed of solid particles, usually of carbon, brought to vivid incandescence. We may, however, divide them into two broad classes, according as the incandescent particles are heated by their own combustion or by extraneous means. The first class, therefore, may be regarded as composed of luminous flames, such as candles, lamps, ordinary gas flames, and the like; while the second consists of illuminants in which a solid is rendered incandescent, it is true, but not by means of its own combustion.

The second class thus consists of such illuminants as mantle gas burners, electric incandescent lamps, and the ordinary electric arcs, which really give their light in virtue of the intense heating of the tips of the carbons by the arc, which in itself is relatively of feeble luminosity.

Illumination based on incandescent gas, phosphorescence, and the like is in an early stage of development, and while it is in this direction that we must look for increased efficiency, incandescent illuminants are still the main reliance in artificial lighting. To the examination of flame illuminants, then, we must first address ourselves.

They are interesting as being the earliest sources of artificial light, and, while usually of much less luminous efficiency than the second class referred to, still hold their own in point of convenience, portability, and ease of extreme subdivision.

We have no means of knowing the earliest sources of artificial light as distinguished from heat. The torch of fat wood was a natural development from the fire on the hearth. But even in Homeric times there is clear evidence of fire in braziers for the purpose of lighting, and there is frequent mention of torches. The rope link saturated with pitch or bitumen was a natural growth from the pine-wood torch, and was later elaborated into the candle.

It is clear that both lamps and candles date far back toward prehistoric times, the lamp being perhaps a little the earlier of the two. At the very dawn of ancient civilization man had acquired the idea of soaking up animal or vegetable fats into a porous wick and burning it to obtain light, and the use of soft fats probably preceded the use of those hard enough to form candles conveniently.

The early lamps took the form of a small covered basin or jar with one or more apertures for the wick and a separate aperture for filling. They were made of metal or pottery, and by Roman times often had come to be highly ornamented. Fig. 34

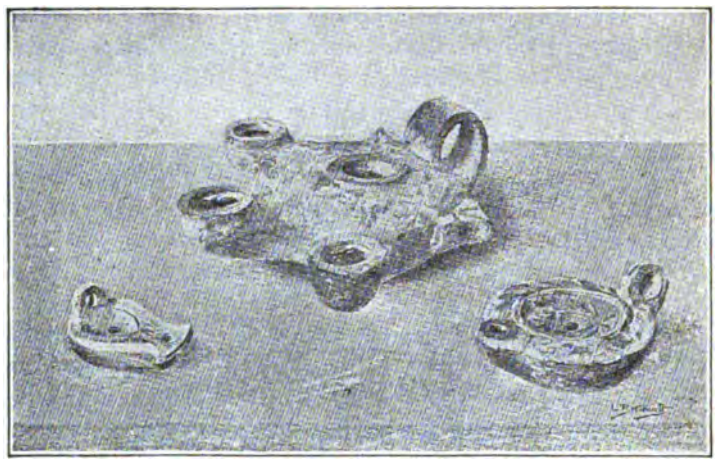


Fig. 34. — Early Roman Lamps.

shows a group of early Roman lamps of common pottery, and gives a clear idea of what they were. They rarely held more than one or two gills, and must have given at best but a flickering and smoky light. Fig. 35 shows a later Roman lamp of fine workmanship in bronze.

In very early times almost any fatty substance that would burn was utilized for light, but in recent centuries the cruder fats have gone out of general use, and new materials have been added to the list. It would be a thankless task to tabulate the properties of all the solids and liquids which have been burned as illuminants, but those in practical use within the century just passed may for convenience be classified about as follows:

FLAME ILLUMINANTS.

Fats and Waxes.	Fats and Waxes.
Tallow (stearin).	Olive oil.
Sperm oil (whale oil).	Colza oil.
Spermaceti.	Beeswax.
Lard oil.	Vegetable waxes.

Petroleum.

The true fats are chemically glycerides, i.e., combinations of glycerin with the so-called fatty acids, mainly stearic, oleic, and palmetic. The waxes are combinations of allied acids with bases

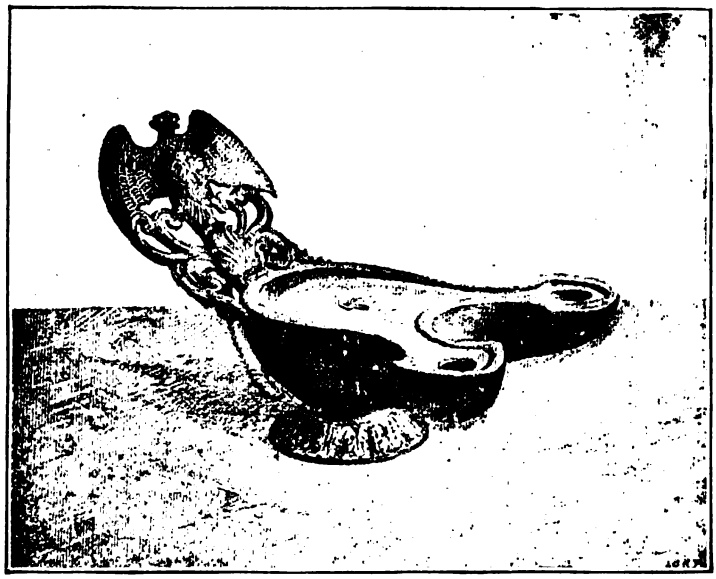


Fig. 35. — Roman Bronze Lamp.

somewhat akin to glycerin, but of far more complicated composition. Technically, spermaceti is allied to the waxes, while some of the vegetable waxes belong chemically with the fats.

All these substances, solid or liquid, animal or vegetable, are very rich in carbon. They are composed entirely of carbon, hydrogen, and oxygen, and as a class have about the following percentage composition by weight: carbon, 76 to 82 per cent; hydrogen, 11 to 13 per cent; oxygen, 5 to 10 per cent.

They are all natural substances which merely require to go

through a process of separation from foreign matter, and sometimes bleaching, to be rendered fit for use.

An exception may be made in favor of "stearin," which is obtained by breaking up chemically the glycerides of animal fats and separating the fatty acids before mentioned from the glycerin. The oleic acid, in which liquid fats are rich, is also gotten rid of in the commercial preparation of stearin in order to raise the melting point of the product.

In a separate class stand the artificial "burning fluids" used considerably toward the middle of the nineteenth century. As they are entirely out of use, they scarcely deserve particular classification. Their base was usually a mixture of wood alcohol and turpentine in varying proportions. From its great volatility such a compound acted almost like a gas generator; the flame given off was quite steady and brilliant, with much less tendency to smoke than the natural oils, but the "burning fluids" as a class were outrageously dangerous to use, and fortunately were driven out by the advent of petroleum and its products.

Petroleum, which occurs in one form or another at many places on the earth's surface, has been known for many centuries, although not in large amounts until recently. Bitumen is often mentioned by Herodotus and other early writers, and in Pliny's time mineral oil from Agrigentum was even used in lamps.

But the actual use of petroleum products as illuminants on a large scale dates from a little prior to 1860, when the American and Russian fields were developed with a common impulse. Crude petroleum is an evil-smelling liquid, varying in color from very pale yellow to almost black, and in specific gravity from 0.77 to 1.00, ranging commonly from 0.80 to 0.90.

Chemically it is composed essentially of carbon and hydrogen, its average percentage composition being about as follows: carbon, 85 per cent; hydrogen, 15 per cent. It is composed in the main of a mixture of the so-called paraffin hydrocarbons, having the general formula C_nH_{2n+2}, and the members of this series found in ordinary American petroleum vary from methane (CH_4) to pentadecane ($C_{15}H_{32}$), and beyond to solid hydrocarbons still more complicated. Petroleum from the Texas and neighboring fields and from the Russian fields is generally less rich in the paraffin series and contains members of other hydrocarbon series in consid-

erable amounts, yielding interesting and valuable products, but less of high-grade illuminating oils.

To fit petroleum for use as an illuminant, these component parts have to be sorted out, so that the oil for burning shall neither be so volatile as to have a dangerously low flashing point nor so stable as not to burn clearly and freely.

This sorting is done by fractional distillation. The following table gives a general idea of the products arranged according to their densities:

	Substance.	Density.	Use.
Petroleum ether.	Cymogene,	0.59	Small, as solvents.
	Rhigoline,	0.63	
	Gasoline,	0.65	Gas, explosion engines.
Petroleum spirit	Benzine naphtha,	0.68	Gas lamps, engines.
	Naphtha,	0.71	Cleaning, engines.
	Benzine,	0.74	Varnish, etc.
Kerosene.....	Kerosene of various grades,	0.78 to 0.81	Illumination.
Oils.....	Lubricating oils of various grades,	0.87 to 0.93	Lubrication.
Solids.....	Vaseline,		Emollient.
	Paraffin,		Candles, insulation, waterproofing, etc.

"Petroleum ether" and "petroleum spirit" find little direct use in illumination, for they are so inflammable as to be highly dangerous, and form violently explosive mixtures with air at ordinary temperatures.

Kerosene should be colorless, without a very penetrating odor, which indicates too great volatility, and should not give off inflammable vapor below a temperature of 120° F., or, better still, below 140° F. to 150° F. Oils of the latter grades are pretty safe to use, and are always to be preferred to those more volatile. The yield of kerosene from crude oil varies from place to place, but with good American oil runs as high as 50 to 75 per cent.

Paraffin is sometimes used unmixed for making candles, but is preferably mixed with other substances, like stearin, to give it a higher melting point.

Having thus casually looked over the materials burned in candles and lamps, the results may properly be considered.

Candles. — These are made usually of stearin, paraffin, wax, or mixtures of the first two substances. They are molded hot in

automatic machines, and, as usually supplied in this country, are made in weights of 4, 6, and 12 to the pound. Spermaceti candles are also made, but are little used except for a standard of light. The old English standard candle is of spermaceti, weighing one-sixth of a pound and burning at the rate of 120 grains per hour.

Commercial candles give approximately 1 candle power, sometimes rather more, and burn generally from 110 to 130 grains per hour. As candles average from 15 to 18 cents per pound, the cost of 1 candle hour from this source amounts to about 0.25 cent to 0.30 cent. This is obviously relatively very expensive, although it must not be forgotten that candles subdivide the light so effectively that for many purposes 16 lighted candles are very much more effective in producing illumination than a gas flame or incandescent lamp of 16 candle power.

The present function of candles in illumination is confined to their use as portable lights, for which, on the score of safety, they are far preferable to kerosene lamps, and to cases in which, for artistic purposes, thorough subdivision of light is desirable. Where only a small amount of general light is needed, candles give a most pleasing effect, and are, moreover, cleanly and odorless.

In efficiency candles leave much to be desired. For, taking the ordinary stearin candle as a type, it requires in dynamical units the equivalent of about 90 watts per candle power, consumes per hour the oxygen contained in 4.5 cubic feet of air, and gives off about 0.6 cubic foot of carbonic acid gas. In these respects the candle is inferior to the ordinary lamp, and still more inferior to gas or electric lights. Nevertheless, it is oftentimes a most convenient illuminant.

Oil Lamps. — Oils other than kerosene are used in this country only to a very slight extent, the latter having driven out its competitors. Sperm oil and, abroad, colza oil (obtained from rapeseed) are valued as safe and reliable illuminants for lighthouses, and in some parts of the Continent olive oil is used in lamps, as it has been from time immemorial.

Here, kerosene is still the general illuminant outside of the cities and larger towns. It has the merits of being cheap (on the average 12 cents to 15 cents per gallon in recent years), safe, *if of the best quality*, and of giving, when properly burned, a very steady and brilliant light.

All oils require a liberal supply of air for their combustion, particularly the heavier oils, and many ingenious forms of lamp have been devised to meet the requirements. On the whole, the most successful are on the argand principle, using a circular wick with air supply both within and without, although some of the double flat-wick burners are admirable in their results. A typical burner, the familiar "Rochester," is shown in Fig. 36, which sufficiently shows the principle involved. In kerosene lamps the capillary action of the wick affords an ample supply of oil, but with some other oils it has proved advantageous to provide a forced supply.



Fig. 36. — "Rochester" Kerosene Burner.

The so-called "student lamp," with its oil reservoir, is the survival of an early form of argand burner designed to burn whale oil, and gives a particularly fine and steady light. In other instances clockwork is employed to pump the oil, and sometimes a forced-air supply is used.

Kerosene lamps usually are designed to give from 10 to 20 candle power, and occasionally more, special lamps giving even up to 50 or 60 candle power. The consumption of oil is generally from 50 to 60 grains per hour per candle power. As kerosene weighs about 6.6 pounds per gallon, the light obtained is in the neighborhood of 800 candle hours per gallon.

This brings the cost of the candle hour down to about 0.018

cent for material consumed, taking the oil at 15 cents per gallon. No illuminants save arc lights, metallic filament incandescents, and mantle burners with cheap gas can compare with it in point of economy.

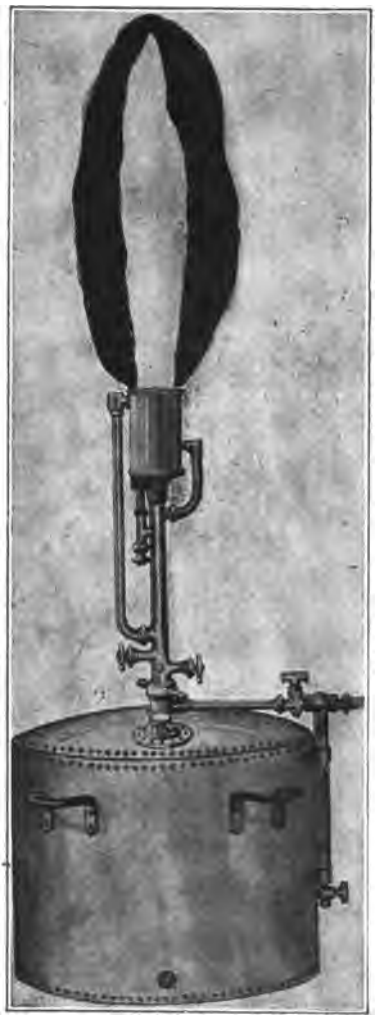


Fig. 37. — "Lucigen" Torch.

A very interesting and valuable application of oil lighting is found in the so-called "Lucigen" torch and several kindred devices. The oil, generally one of the heavier petroleum products, is carried under air pressure in a good-sized portable reservoir, and the oil is led, with the compressed air strongly heated by its passage through the apparatus, to an atomizing nozzle, from which it is thrown out in a very fine spray, and is instantly vaporized and burned under highly efficient conditions.

These "Lucigen" torches give nearly 2000 candle power on a consumption of about two gallons of oil per hour, burning with a tremendous flaring flame three feet or more in length and six or eight inches in diameter. They are very useful for lighting excavations and other rough works for night labor, being powerful, portable, and cheap to operate. Fig. 37 gives an excellent idea of this apparatus in a common form. Such a light is suited only to outdoor work, but it forms an interesting transitional step toward the air-gas illuminants which have come into considerable use for lighting where service mains for gas or electricity are not available, or where the conditions confer special economy.

Air Gas. — It has been known for seventy years or more that the vapor of volatile hydrocarbons could be used to enrich poor coal gas, and that even air charged with a large amount of such vapor was a pretty good illuminant.

Of late years this has resulted in the considerable use of "carburetors," which saturate air with hydrocarbon vapor, making a mixture too rich to be readily explosive and possessing good illuminating properties when burned as gas in the ordinary way.

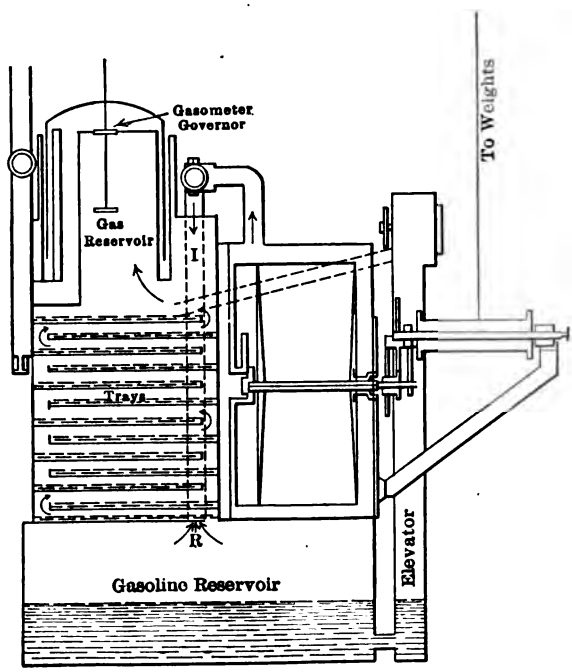


Fig. 38. — Gasoline Gas Machine.

The usual basis of operations is commercial gasoline, which consists of a mixture of the more volatile paraffin hydrocarbons, chiefly pentane, hexane, and isohexane.

The process of gas making is very simple, consisting merely of charging air with the gasoline vapor. Fig. 38 shows in section a typical air-gas machine. It consists of a large metal tank holding a supply of gasoline, a carbureting chamber of flat trays over which a gasoline supply trickles, a fan to keep up the air supply, and a little gas reservoir in which the pressure is regulated and

from which the gas is piped. The fan is usually driven by heavy weights, wound up at suitable intervals.

The whole gas machine is usually put in an underground chamber, both for security from fire and to aid in maintaining a steady temperature. About six gallons of gasoline are required per 1000 cubic feet of air, and the result is a gas of very fair illuminating power, rather better than ordinary city gas.

The cost of this air gas is very moderate, but on account of the cost of plant and some extra labor, it is materially greater than the cost of direct lighting by kerosene lamps. It is a means of lighting very useful for country houses and other places far from gas or electric supply companies. The principal difficulty is the variation of the richness of the mixture with the temperature, owing to change in the volatility of the gasoline, a fault which is very difficult to overcome. At low temperatures there is a tendency to carburet insufficiently and to condense liquid in the cold pipes. The gas obtained from these machines is burned in the ordinary way, although burners especially adapted for it are extensively employed. In recent years such gas has been considerably used with mantle burners, obtaining thus a very economical result. The air gas just described is too rich in gasoline vapor to be an explosive mixture, the limits of danger being between 2 and 5 per cent of gasoline vapor, and the mixture described being well above the upper limit. Abroad air gas so lean as to be below the lower limit of danger has come into use, carrying say 1.5 per cent gasoline vapor instead of 10 to 15 per cent. Such gas is fit only for use in mantle burners, but is cheap and safe.

Coal Gas. — In commercial use for nearly a century, coal gas was, until about twenty-five years ago, the chief practical illuminant. Little need here be said of its manufacture, which is a department of technology quite by itself, other than that the gas is obtained from the destructive distillation of rich coals inclosed in retorts, from which it is drawn through purifying apparatus and received in the great gasometers familiar on the outskirts of every city.

The yield of gas is about 10,000 cubic feet per ton of coal of good quality. The resulting gas consists mainly of hydrogen and of methane (CH_4), with small amounts of other gases, the composition varying very widely in details while preserving the same general characteristics. A typical analysis of standard coal gas

giving 16 to 17 candle power for a burner consuming 5 cubic feet per hour would be about as follows:

Hydrogen	53.0
Paraffin hydrocarbons	33.0
Other hydrocarbons	3.5
Carbon monoxide	5.5
Carbon dioxide	0.6
Nitrogen	4.2
Oxygen	0.2
	100.0

Ammonia compounds, carbon dioxide, and sulphur compounds are the principal impurities which have to be removed. Traces of these and of moisture are regularly found in commercial gas. Sulphur dioxide (SO_2) is the most persistent impurity and perhaps the most objectionable.

In point of fact, at the present time but a small proportion of the illuminating gas used in this country is unmixed coal gas, such as might show the analysis just given. Most of it is water gas, or a mixture of coal gas and water gas. Water gas is produced by the simple process of passing steam through a mass of incandescent coal or coke, and thus breaking up the steam into hydrogen and oxygen, which latter unites with the carbon of the coal, forming carbon monoxide.

At moderate temperatures considerable carbon dioxide would be formed, but, as this is worse than useless for burning purposes, the heat is always carried high enough to insure the formation of the monoxide. The hypothetical chemical equation is:

$$H_2O + C = CO + H_2.$$

The reaction is never clean in so complete a sense as this, some CO_2 always being formed. This water gas as thus formed is useless as an illuminant, and requires to be enriched by admixture of light-producing hydrocarbons — carbureted, in other words. This is done by treating it to a spray of petroleum in some form, and at once passing the mixture through a superheater, which breaks down the heavier hydrocarbons and renders the mixture stable.

There are many modifications of this system worked on the same general lines. The enriching is carried to the extent necessary to meet the legal requirements, usually producing gas of 15 to 20 candle power for a 5-foot jet. A typical analysis of the water gas after enriching would show about the following by volume:

Hydrogen	34.0
Methane	15.0
Enriching hydrocarbons	12.5
Carbon monoxide	33.0
Oxygen, nitrogen, CO_2, etc.	5.5
	100.0

The latter part of the enriching process, i.e., superheating and breaking up the heavy hydrocarbons while in the form of vapor, is substantially that used in making Pintsch and allied varieties of oil gas, so that commercial water gas may be regarded as a mixture of water gas and oil gas. The "cracking" of heavy oils by heat has proved a convenient means of increasing the available amount of lighter hydrocarbons from petroleum. The lightest gaseous products are sometimes separated and compressed to liquefaction in steel cylinders, thus furnishing an easily transportable and convenient source of gas for light and heat. Such is the so-called "Blau-gas" and some analogous products in commercial use to a limited extent.

Water gas, when properly enriched, is fully the equivalent of coal gas for illuminating purposes. The main difference between them is the very large proportion of carbon monoxide in the water gas, which adds greatly to the danger of leaks.

For carbon monoxide is an active poison, not killing merely by asphyxia, but by a well-defined toxic action peculiar to itself. Hence persons overcome by water gas very frequently die under circumstances which, if coal gas were concerned, would result only in temporary insensibility. As the enriched water gas is cheaper than coal gas, however, the gas companies, maintaining, with some justice, that gas is not furnished for breathing purposes, supply it unhesitatingly — sometimes openly, sometimes without advertising the fact.

Very commonly so-called coal gases contain enriched water gas to bring up their illuminating power. In these cases the carbon monoxide is in much less proportion, perhaps only 10 to 15 per cent.

It is often stated that water gas is doubly dangerous from its lack of odor. The unenriched gas is practically odorless, but when enriched the odor, while less penetrating than that of coal gas, is sufficiently distinctive to make a leak easily perceptible.

Gas burners for ordinary illuminating gas are of three general types: flat flame, argand, and regenerative. The first named is

the most common and least efficient form. It consists of two general varieties, known respectively as the "fishtail" and "bat's-wing." The former has a concave tip, usually of steatite or similar material, containing two minute round apertures, so inclined that the two little jets meet and flatten out crosswise into a wide flame. This form is now relatively little used save in dealing with some special kinds of gas.

The bat's-wing burner, with a dome-shaped tip, having a narrow slit for the gas jet, is the usual form employed with ordinary gas. Flat-flame burners work badly in point of efficiency unless of fairly large size. On ordinary gas of 14- to 17-c.p. nominal value on a 5-foot burner, burners taking less than about 4 cubic feet per hour are decidedly inefficient. A 4-foot burner will give about 2.5 candles per foot, while a 5-foot burner will give 2.75 to 3 candle power per foot.

The argand burners give considerably better results, their flames being inclosed and protected from draughts by a chimney; and the air supply being good the temperature of the flame is high and the light is whiter than in the flat-flame burners. The principle is familiar, the wick of the argand oil lamp being replaced in the gas burner by a hollow ring of steatite connected with the supply, and perforated with tiny jet holes around the upper edge. Fig. 39 shows in section an argand burner (Sugg's) of a standard make used in testing London gas. This burner uses 5 cubic feet per hour, and the annular chamber has 24 holes, each 0.045 inch in diameter. The efficiency is a little better than that of the flat-flame burners, running, on good gas, from 3 to 3.5 candle power per foot. The London legal standard gas is of 16 candle power in this 5-foot burner.

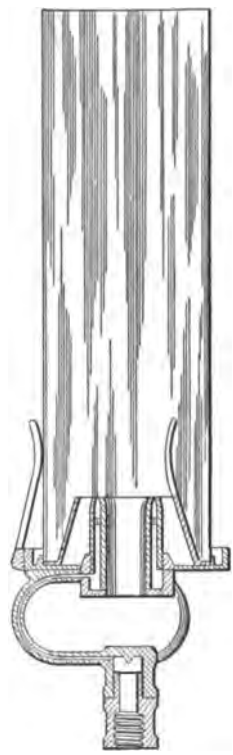


Fig. 39. — Section of Argand Gas Burner.

On rich gas the flat-flame burners, particularly the fishtail, work better than the argand, the fishtail being better on very rich gas than is the bat's-wing form. With ordinary qualities

of gas, however, the argand burner is vastly more satisfactory than the flat flames.

For very powerful lights the so-called regenerative burners are generally preferred. These are based on the general principle of heating both the gas and the air furnished for its combustion prior to their reaching the flame. The burner proper is something like an inverted argand, so arranged as to furnish a circular sheet of flame turned downward, and with, of course, a central cusp. Directly above the burner, and strongly heated by the flame, are the air and gas passages.

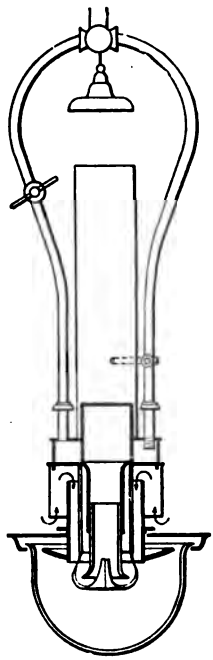


Fig. 40. — Wenham Regenerative Burner.

Fig. 40 shows in section the Wenham burner of this class. The arrows show the course of the air and the gas, the latter being burned just below the iron regenerative chamber and the products of combustion passing upward through the upper shell of the lamp, and preferably to a ventilating flue. The globe below prevents the access of cold air, and an annular porcelain reflector surrounding the exit flue turns downward some useful light.

The Siemens regenerative burner, arranged upon a similar plan and shown in Fig. 41, gives much the same effect. The regenerative burners of this class give a very brilliant yellow-white light with a generally hemispherical distribution downward. They work best and most economically in the larger sizes, — 100 to 200 candle power, — and must be placed near the ceiling to take the best advantage of their usual distribution of light.

With gas of about 16-candle-power standard these regenerative burners consume only about 1 cubic foot per hour for 7 to 10 candle power. They are thus more than twice as economical as the best argand burners. Their chief disadvantage lies in the fact that to get this economy very powerful burners must be used, of a size not always conveniently applicable.

From such a powerful center of light a large amount of heat is thrown off, obviously less per candle power of light than in other gas burners, but, in the aggregate, large. Regenerative

burners have done good service in the illumination of large spaces, although at the present time the greater economy of the mantle burner has pushed the regenerative class into the background. Their light, nevertheless, is of a more pleasing color than that given by the mantle burners.

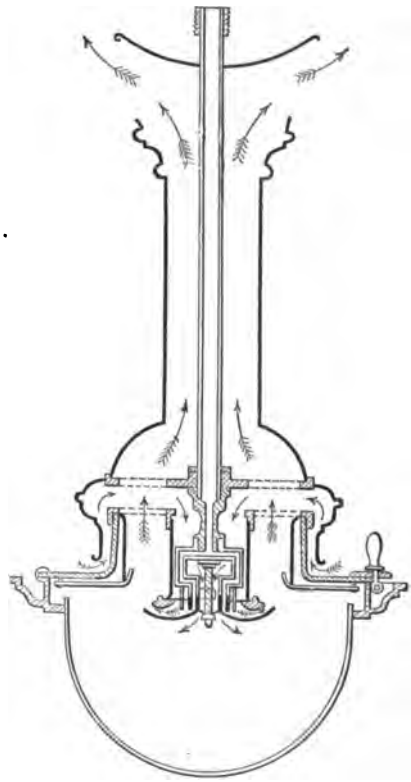


Fig. 41. — Siemens Regenerative Gas Burner.

The most recent and in some respects most important addition to the list of flame illuminants is *acetylene*. This gas is a hydrocarbon having the formula C_2H_2, which has been well known to chemists for many years, but which until recently has not been preparable by any convenient commercial process. It is a rather heavy gas, of evil odor, generally somewhat reminiscent of garlic, and, being extremely rich in carbon uncombined with oxygen (nearly 93 per cent by weight), it burns very brilliantly when properly supplied with air. Its flame is intensely bright, nearly white in color, and for the light given it vitiates the air in comparatively small degree.

Acetylene is made in practice from calcic carbide, CaC_2, a chemical product prepared by subjecting a mixture of powdered lime and carbon (coke) to the heat of the electric furnace. By this means it can be prepared readily in quantity at moderate cost. The acetylene is made from the calcic carbide by treating it with water, lime and acetylene being the results of the reaction, which, in chemical terms, is as follows:

$$CaC_2 + 2\,H_2O = Ca(OH)_2 + C_2H_2.$$

Commercial calcic carbide is far from being chemically pure, so that the acetylene prepared from it contains various impurities, and is neither in quantity nor quality just what the equation would indicate. The carbide is extremely hygroscopic, and hence not very easy to transport or keep, and the upshot of this property and the inherent impurities is that the practical yield of acetylene is only about 4.5 to 5.0 cubic feet per pound of carbide, 4.75 cubic feet being an extremely good average unless the work is on a very large scale, though 4.5 cubic feet is the more usual yield. In theory the yield should be nearly 5.5 cubic feet per pound.

The gaseous impurities are quite varied and by no means uniform in amount or nature, but the most objectionable ones may be removed by passing the gas in fine bubbles through water. If the gas is being prepared on a large scale it can readily be purified.

Acetylene has the disadvantage of being somewhat unstable. It forms direct compounds with certain metals, notably copper, these compounds being known as acetylides, and being themselves so unstable as to be easily explosive. Acetylene should be therefore kept out of contact with copper in storage, and even in fixtures.

The gas itself is easily dissociated with evolution of heat into carbon and hydrogen, and hence may be inherently explosive under certain conditions, fortunately not common.

At atmospheric pressure, or at such small increased pressures as are employed in the commercial distribution of gas, acetylene, unmixed with air, cannot be exploded by any means ordinarily at hand.

Above a pressure of about two atmospheres acetylene is readily explosive from high heat and from a spark or flame, and grows steadily in explosive violence as the initial pressure rises, until when liquefied it detonates with tremendous power if ignited. At ordinary temperatures it can be liquefied at a pressure of about 80 atmospheres, and it has been proposed to transport and store it in liquid form. But, although even when liquefied it will not explode from mechanical shock alone, it is in this condition an explosive of the same order of violence as guncotton or nitroglycerin, and should be treated as such.

Mixtures of acetylene and air explode violently, just as do

mixtures of illuminating gas and air. The former begin to explode rather than merely burn, when the mixture contains about one volume of acetylene to three of air, detonate very violently with about nine volumes of air, and cease to explode with about twenty volumes of air.

Ordinary coal gas begins to explode when mixed with three volumes of air, reaches a maximum of violence with about five to six volumes, and ceases to explode with eleven volumes. Of the two gases, the acetylene is rather the more violently explosive when mixed with air, and it becomes explosive while the mixture is much leaner. The difference is not of great practical moment, however, except as acetylene generators, being easily operated, are likely to get into unskillful hands. This fact has already resulted in many disastrous explosions.

As regards its poisonous properties, acetylene seems to be somewhat less dangerous than coal gas and very much less dangerous than water gas. Properly speaking, acetylene is but very feebly poisonous when pure, and has such an outrageous smell when slightly impure that the slightest leak attracts attention. Some early experiments showed highly toxic properties, but these have not been fully confirmed, and may have been due to impurities in the gas — possibly to phosphine, which is a violent poison.

The calcic carbide from which the acetylene is prepared is so hygroscopic and gives off the gas so freely that it has to be stored with great care on account of possible danger from fire. Fire underwriters are generally united in forbidding entirely the use or storage of liquid or compressed acetylene, or the storage of any but trivial amounts of calcic carbide (a few pounds) except in detached fireproof buildings.

Acetylene is, when properly burned, a magnificent illuminant. It will not work in ordinary burners, for unless very liberally supplied with air it is so rich in carbon as to burn with a smoky flame and a deposit of soot. It must actually be mixed with air at the burner in order to be properly consumed. When so utilized its illuminating power is very great. The various experiments are not closely concordant, but they unite in indicating an illuminating power of 35 to 50 candle hours per cubic foot, according to the capacity of the burner, the larger burners, as usual, working the more economically.

This means that the acetylene has nearly fifteen times the

illuminating power of a good quality of ordinary illuminating gas when burned in ordinary burners. It will, consequently, give about six to eight times more light per cubic foot than gas in a regenerative burner, and, it may be mentioned, about three to four times more light than gas in a mantle (Welsbach) burner.

Fig. 42 shows a common standard form of acetylene burner, intended to consume about 0.5 cubic foot per hour. It is a duplex form akin in its production of flame to a common fishtail. Each of the two burners is formed with a lava tip having a slight constriction close to its point. In this is the central round aperture for the gas, and just ahead of it are four lateral apertures for the air supply. The acetylene and air mix just in front of the constriction and the two burners unite their jets to form a small, flat flame. It is in effect a pair of tiny Bunsen burners inclined to produce a fishtail jet.

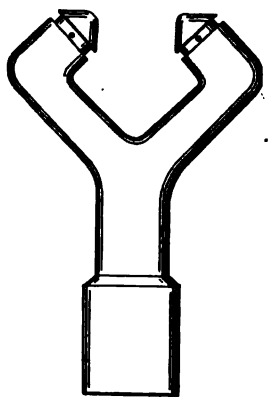


Fig. 42. — Acetylene Burner.

Larger acetylene burners are worked on a similar principle, all having the air-supply passages characteristic of the Bunsen burner. Too great air supply for the acetylene gives the ordinary colorless Bunsen flame, but on reducing the amount the acetylene burns with a singularly white, brilliant, and steady flame.

Of acetylene generators designed automatically to supply gas at constant pressure from the calcic carbide the name is legion. A vast majority of those in use at present are of rather small capacity, being designed for a few lights locally or as portable apparatus for lamps used for projection.

A very useful type of the small generator is shown in Fig. 43, a form devised by d'Arsonval. It consists of a small gasometer with suitable connections for taking off the gas and drawing off the water. The bell of the gasometer is furnished at the top with a large aperture closed by a water seal. Through this is introduced a deep iron-wire basket containing the charge of carbide.

The acetylene is generated very steadily after the apparatus gets to working and the pressure is quite uniform. The water in the gasometer of the d'Arsonval machine is covered by a layer of oil, which serves an important purpose. When one ceases using

the gas the bell rises, and as the carbide basket rises out of the water the oil coats it and displaces the water, checking further evolution of gas. The oil also checks evaporation, so that there is no slow evolution of gas from the absorption of aqueous vapor.

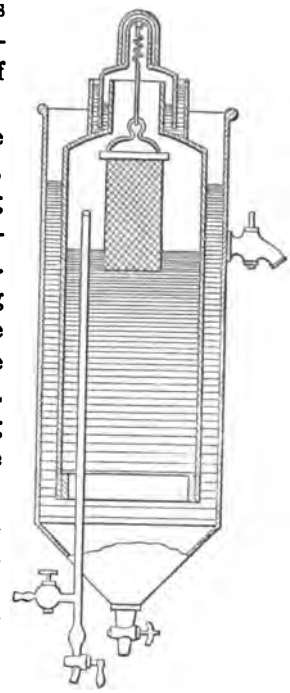


Fig. 43. — Small Acetylene Generator.

Acetylene generators on a larger scale are operated on much the same principle, although the generating and regulating parts of the apparatus are commonly separated instead of being united as in Fig. 43, and there is often means for washing the gas. The principle adopted in the larger generators is uniformly to feed the calcic carbide in small quantities in a large excess of water, thereby avoiding the overheating which would follow were water dropped on an excess of carbide.

Fig. 44 shows in section a typical acetylene apparatus for medium-sized plants such as used for house lighting. It consists of a generator tank, a carbide holder from which the granulated carbide is automatically fed in small quantities, a regulating gasometer, and the necessary piping, valves, and water seal to facilitate and insure the safe and convenient handling of the output. Such apparatus runs with very little attention and is largely used in country houses and hotels out of reach of gas and electric supply, and even as a matter of economy where the gas supply is indifferent in quality or too high in price.

Isolated plants of capacity as high as 5000 burners have been installed for service in large hotels. Occasionally a fairly large plant is found in village lighting, but for the most part the equipments as generally found are for a few score or hundred burners. These acetylene generators as now furnished are very nearly automatic in their action, but at times require a little intelligent care to keep them in first-class working order, as they are not yet entirely foolproof, so that while the labor and upkeep cost is small it is not negligible.

Acetylene has a calorific value of about 1440 B.t.u. and has been successfully applied to the production of enormously high temperatures by burning it with oxygen as a substitute for the older oxyhydrogen flame. Used in this way, it gives a blowpipe flame capable of most valuable service in welding, cutting steel plates and beams, and other sensational feats requiring extreme temperature. Even the ordinary flame temperature of acetylene is in the neighborhood of 2200° C.

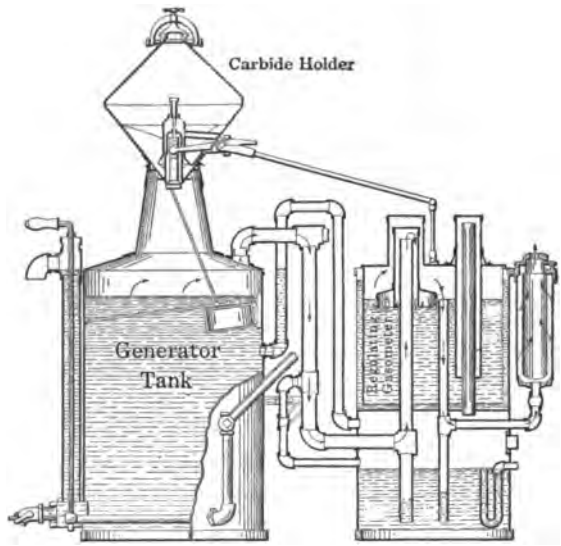


Fig. 44. — Type of Acetylene Generator Used for Medium-sized Plants and House Lighting.

Acetylene is particularly well adapted for supplying portable lights in virtue of the great ease with which it can be stored in solution. It is not a good thing to store under simple pressure, but it can be stored in solution very simply and safely. Acetone absorbs acetylene greedily, as water takes up ammonia, so that at ordinary temperature and pressure 25 volumes of gas are taken up by one volume of liquid, and under pressure proportionately more.

To avoid the inconvenience of dealing with a liquid and to increase security against explosion, the pressure cylinders used for the acetone solution are filled with very porous asbestos disks

which still leave 80 per cent of the real capacity for the acetylene-acetone solution, which is carried up to a pressure of about ten atmospheres. A cylinder so charged contains an amount of acetylene equivalent at atmospheric pressure to 100 times its volume. Hence a cylinder of no more than half a cubic foot capacity can supply a 40-candle-power burner for something like 100 hours of continuous service. Acetylene thus stored has come into very large use for lighting motor cars, portable lamps, buoys, and other purposes where a convenient and powerful portable source of light is needed.

At the present time, in fact, acetylene is practically the only flame illuminant which must be seriously taken into consideration by the illuminating engineer. For furnishing portable lights of considerable power it is easily the most convenient source available, and in an emergency a good automobile light burning acetylene from the usual storage tanks is capable of doing immensely efficient service in lighting up night work of various kinds; and it is available in any city on extremely short notice.

As to the value of acetylene, it is evidently worth about fifteen times as much per cubic foot as gas burned in ordinary burners, or three to four times as much as gas, assuming the latter to be burned in Welsbach burners. Now, one ton of calcic carbide of high quality, efficiently used, will produce between 9000 and 10,000 cubic feet of acetylene, equal in illuminating value to 150,000 cubic feet of gas in the one case or to 30,000 to 40,000 cubic feet in the other.

The cost of the calcic carbide is a very uncertain quantity at present. The best authorities bring the manufacturing cost, on a large scale and under very favorable circumstances, somewhere between $30 and $40 per ton. It is doubtful if any finds its way into the hands of bona-fide users at less than about $60 per ton, and the current price in small lots is much higher, and naturally so, by reason of troublesome storage and the cost of transportation. Adding the necessary allowance for the cost of producing the gas from the carbide, it is at once evident that the cost of lighting by acetylene falls materially below that of lighting by common gas in ordinary burners at the common price of $1 to $1.50 per 1000 feet.

It is equally evident that it considerably exceeds the cost of gas lighting by Welsbach burners. Acetylene is to some extent

used in mantle burners, but it is a question whether the moderate increase in efficiency overbalances the practical difficulties which have been found. Its cost of production and distribution does not yet render it commercially attractive under ordinary conditions of supply from gas and electric central distributing plants.

Nevertheless, acetylene is, for use in isolated places, one of the very best and most practical illuminants; for it is fairly cheap, easily made, and gives a light not surpassed in quality by any common artificial illuminant save the "intensified" electric arc. It is peculiarly well adapted for temporary and portable use, giving as it does a very brilliant and steady light, well suited for use with reflectors and projecting apparatus, admirable in color, and very easy of operation.

CHAPTER VI.

THE MATERIALS OF ILLUMINATION — INCANDESCENT BURNERS.

THE general class of illuminants operative by the incandescence of a fixed solid body would include in principle both arc and incandescent electric lamps, as well as those in which the radiant substance is heated by ordinary means. In this particular place, however, it seems appropriate to discuss the latter forms only, leaving the electric lights for a separate chapter.

Incandescent radiants brought to the necessary high temperature by a nonluminous flame have their origin in the so-called "Drummond" or "lime" light, which has been used for many years as the chief illuminant in projection, scenic illumination on the stage, and such like purposes, and which has only recently been extensively replaced by the electric arc. The limelight consists of a short pencil of lime against which is directed the colorless and intensely hot flame from a blast lamp fed with pure oxygen and hydrogen, or more commonly with oxygen and illuminating gas.

The general arrangement of the oxyhydrogen burner is shown in Fig. 45. Here *A* and *B* are the supply pipes for the oxygen and hydrogen, fitted with stopcocks. These unite in a common jet in the burner *C*, which is usually inclined so as to bring the burner where it will not cast a shadow. Sometimes the two gases are mixed in the burner tube *C*, and sometimes the hydrogen is delivered through an annular orifice about a central tube which supplies the oxygen. The pencil of lime is carried on a holder *D*, and the whole burner is often carried on an adjustable stand *E*, so that it can be raised, lowered, or turned, as occasion demands. The mixed gases unite in a colorless, slender flame of enormously high temperature, and when this impinges on the lime the latter rises in a small circular spot to the most brilliant incandescence, giving an intense white light of, generally, 200 to 400 candle power.

The light, however, falls off in brilliancy quite rapidly, particularly when the initial incandescence is very intense, losing

something like two-thirds of its candle power in an hour, so that it is the custom for the operator to turn the pencil from time to time so as to expose new portions to the oxyhydrogen jet.

At the highest temperatures the calcium oxide is somewhat volatile and the surface seems to change and lose its radiative power. Sometimes pencils of zirconium oxide are used instead of lime,

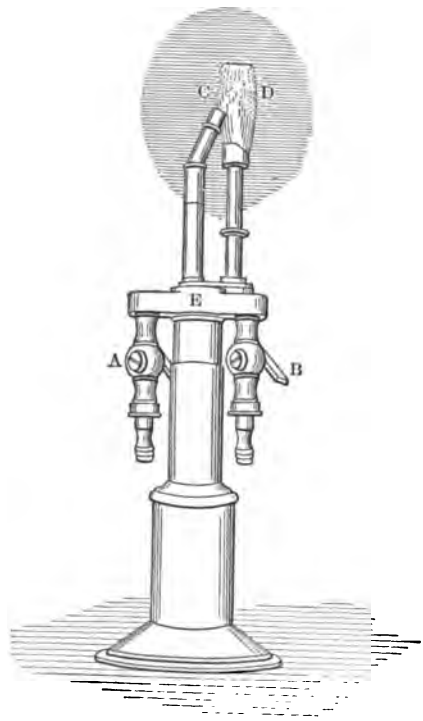


Fig. 45. — Oxyhydrogen Burner.

and this substance has proved more permanently brilliant and does not seem to volatilize. When properly manipulated, the calcium light is beautifully steady and brilliant, and being very portable, is well adapted for temporary use.

From time to time attempts were made to produce a generally useful incandescent lamp in which the oxyhydrogen jet should be replaced by a Bunsen burner requiring only illuminating gas and air.

Platinum gauze and other substances were tried as the incandescent materials, but the experiments came to nothing practically until the mantle burner of Auer von Welsbach appeared. This is generally known in this country as the Welsbach light, but on the Continent as the Auer light. In this burner the material brought to incandescence is a mantle, formed like a little conical bag, of thin fabric thoroughly impregnated with the proper chemicals and then ignited, leaving a coarse gauze formed of the active material.

The composition of this material has been kept more or less secret until recently, and has been varied from time to time as the burner has gradually been evolved into its present state, but has always consisted of the oxides of the so-called "metals of the rare earths" and is actually composed of thoria with a minute percentage of ceria.

These rare earths — zirconia, thoria, glucina, yttria, ceria, and a half-dozen others still less well known — form a very curious group of chemical substances. They are whitish or yellowish very refractory oxides occurring as components of certain rare minerals, and most of them rise to magnificent incandescence when highly heated. The hue of this incandescence differs slightly for the different earths, and they are only slightly volatile at any but very high temperatures. One — erbia — has the property of giving a spectrum of bright bands when highly heated instead of the continuous spectrum usual to incandescent solids, — a property which is shared in less degree by a few of its curious associates.

The present composition of the Welsbach mantle, which is ordinarily about 99 per cent thoria and 1 per cent ceria, is the result of long-continued work over this group of substances by Dr. Auer von Welsbach, who found in purifying thoria for use in mantles that when chemically pure it gave on incandescence very little light. Tracing backward from this point to discover the properties of the impurities which he had gradually eliminated, he found that ceria possessed an extraordinary power of exciting the thoria to most brilliant incandescence. Just how this remarkable effect is produced is a mystery not yet fully fathomed. Dr. Auer's own idea is that the ceria, which is easily oxidized and reduced, in virtue of this property acts as a species of molecular excitant, perhaps going into combination with the thoria at one stage of oxidation and separating at another stage. Whether this

explanation be the final one or not, it is at least a fact that in all cases, and they are quite numerous, in which a small percentage of one body confers the power of intensive radiation on a large percentage of another body, the former is a substance readily assuming several stages of oxidation, and the latter has in general only one stage of oxidation and is highly refractory. At all events, in the Welsbach mantle and in other similar cases one always finds a fireproof oxide combined with an analogous oxide which is a facile oxygen carrier. It has been suggested that the two unite to form a sort of solid solution, and some plausibility is lent to this hypothesis by the curious sensitiveness of the thoria-ceria combination to small changes in the amount of ceria. As opposed to this cataly-

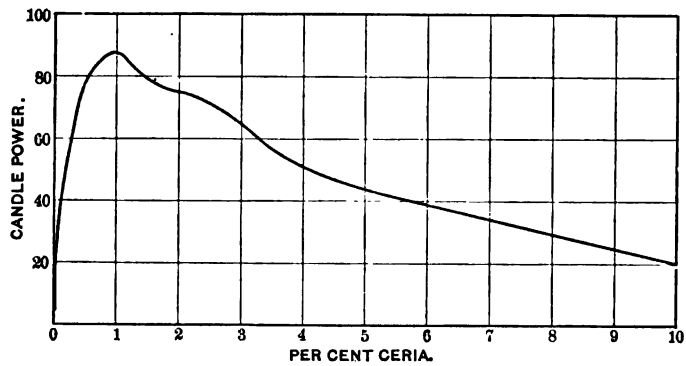


Fig. 46. — Effect on the Candle Power of a Welsbach Mantle of Varying the Amount of Ceria.

tic theory, some recent investigators hold that the action involved is purely physical, the ceria being an extraordinarily good and somewhat selective radiator, which by itself cannot be readily pushed to sufficiently high incandescence for practical efficiency, but which when mixed with the thoria of the mantle, itself a poor radiator but highly refractory, is heated to extreme incandescence. According to this view, it is practically the ceria only which gives the brilliancy to the mantle. There are objections to both theories, and the matter must be considered still unsettled.

Fig. 46, due to Professor Whitaker, shows the effect on the candle power of a Welsbach mantle of varying the amount of ceria. The highest efficiency is reached with a percentage of ceria very close to one per cent, which is the amount commonly found in com-

mercial mantles. With less than one-half per cent the efficiency falls off very rapidly indeed, and noticeably, although more slowly, with amounts of more than one per cent. To the illuminating engineer the theory of the Welsbach mantle is of less importance than its practice, which has completely revolutionized the gas industry within the last decade or two. The standard Welsbach burner as it has been known within this period is shown in Fig. 47, in which the several parts are plainly labeled. It consists essentially of a Bunsen burner with provisions for regulating the air and gas supplies, and the mantle which surrounds the Bunsen flame. There is a gauze tip on the Bunsen burner to prevent the flame striking back, and suitable supports for the shade, chimney, and mantle. The mantle support is permanently adjusted to a cap with a wire-gauze top which goes upon the burner tube with a bayonet joint so that the mantle is brought exactly to the right position. This standard burner uses between 3.5 and 4 cubic feet of gas per hour, and gives with a first-class mantle about 60 mean spherical candle power when the mantle is new and of good quality. The initial efficiency is, therefore, in the neighborhood of 15 candle power per foot of gas. It is, therefore, four or five times as efficient as an open gas burner and two or three times as efficient as the best of the regenerative gas burners, that were, up to the coming of the Welsbach, the most effective gas illuminants. For a long time the Welsbach burner was only available in this unnecessarily powerful form. It consumed, to be sure, less gas than an ordinary fishtail burner, but it gave a great deal more light than was really wanted for most purposes, particularly in domestic lighting, so that the consumer, although getting very cheap light, would have been better satisfied

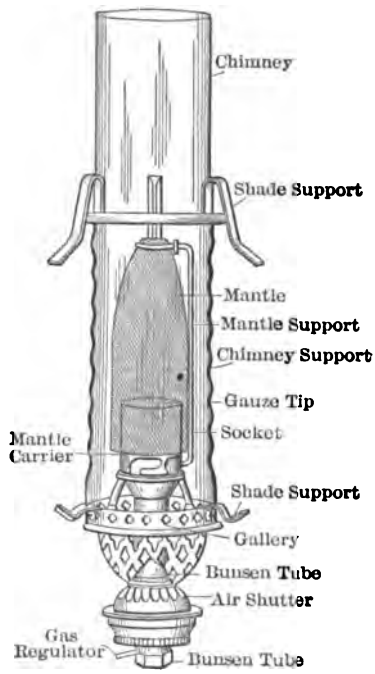


Fig. 47.

with a smaller consumption of gas and a quantity of light better suited to his needs.

In response to this demand, there has been made available within the past three years what is known to the trade as the Junior Welsbach, which is a very much smaller and simpler type of the same structure. It is well shown in Fig. 48. It consists of a Bunsen tube like the larger burner, with a very simple regulator carrying a tube supporting a short perforated mica chimney bearing the mantle already attached in position. The mantle itself is barely 2 inches long and the whole affair about 4 inches, so that it screws on in place of an ordinary burner tip and falls inside the shades previously used for open flames. Chimney, support, and mantle are removed and thrown away when used up, and the total cost of replacement is practically the same as that of the mantle alone in the larger type of burner. These little burners are fully as efficient as their larger predecessors, and with new mantles give between 30 and 35 mean spherical candle power on a consumption of 1.75 to 2 feet of gas per hour, assuming gas of ordinary quality and pressure. In other words, their initial efficiency is in the neighborhood of 15 candle power per cubic foot of gas as in the case of the larger burners. This high figure in so small a burner is due probably to improvements in burner and chimney design and in mantles which have occurred concurrently with the change in size.



Fig. 48.

With the coming of this small unit the last excuse for the use of open gas jets has become invalid. The only possible remaining reason for continuing the use of open jets is the objection to the color of the mantle burner, and even this is rapidly disappearing in the changes of mantle manufacture, of which mention will be made later. The chief fault of the small Welsbach has been the clouding of the mica chimney, which depreciates the candle power of the burner very materially, while the mantle itself is still in first-class condition. This difficulty has been partly at least remedied by slight changes in the dimensions of the chimney, and it is not of any great importance practically, since the replacement is so cheap and the saving of gas so considerable that it is not worth while to work the burner beyond the point of good efficiency from whatever cause.

The statements here made with reference to consumption of gas per initial candle power are necessarily somewhat loose on account of variations in the composition and pressure of the gas and in the manufacture of the mantles themselves. The figures given are based on a good gas of about 20 so-called candle power supplied at the pressure of 2 to 2.5 inches. The efficiency of a given gas in a mantle burner bears no definite relation to its nominal candle power, nor indeed to its thermal value, so that one can deal only in general figures. Variation of an inch of pressure either way will affect the candle power in the corresponding direction somewhat like 20 per cent, and variations of this magnitude are only too common in ordinary gas service. Beside the uncertainty which may arise from varying quality and pressure of gas, it must be remembered that a certain amount of variation must be expected in the mantles themselves, particularly if they are not from the same batch or from the same manufacturer. Gas mantles cannot be readily sorted by actual test burning as are incandescent electric lamps, and consequently may at times show irregular results.

The latest forms of mantle gas burner differ somewhat radically from those just described, in that they are inverted; that is, the Bunsen flame burns upside down and plays upon the interior of a round-bottomed bag-shaped mantle. The result of this arrangement is advantageous, in that the burner thus arranged gives a particularly good distribution of light downward, which is often desirable, and also a materially higher efficiency than the ordinary upright mantle. The gain in efficiency is due chiefly to the fact that the products of combustion are carried more effectively away from the mantle and the supply of air is brought more advantageously to it, so that there is a better surface combustion and a higher incandescence.

A good many difficulties had to be overcome in making this upside-down burner a success. A Bunsen flame has to be very carefully adjusted and regulated in order to burn upside down with any degree of stability, and the carrying of the heat into and around the burner instead of away from it involves some special difficulties. In various ingenious ways these have been for the most part overcome, so that the inverted burner is gradually displacing the older form. A typical inverted Welsbach is shown in cross section in Fig. 49, in which the several parts

are plainly labeled. The mantle is surrounded by a refractory glass chimney with air holes near the lower end for the admission of the air supply, which chimney serves to steady the otherwise somewhat unstable flame; and commonly an outer globe with a hole at the bottom surrounds the chimney proper. To avoid the use of wire gauze over the Bunsen tube to prevent flashing back,

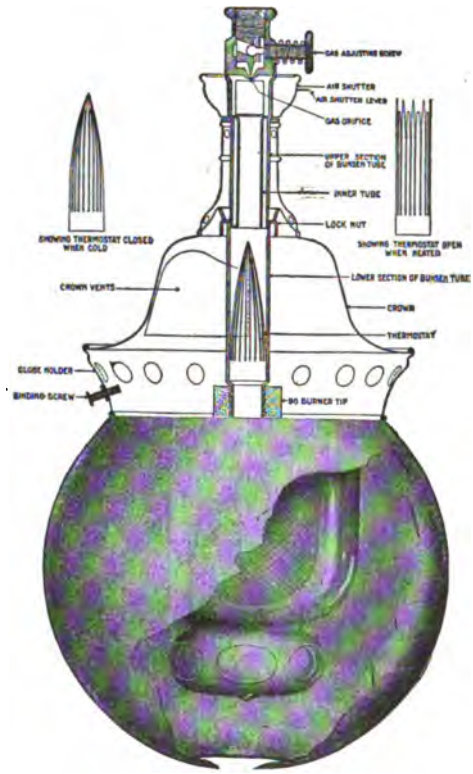


Fig. 49.

a very ingenious automatic thermostat takes its place in the inverted burner. The gauze proved particularly troublesome on this type of burner owing to a tendency to clog, while the thermostat performs the function of the gauze when closed at the first lighting of the burner and afterwards opens up, leaving a clear passage as the burner becomes thoroughly heated. The mantle itself is mounted on a magnesia-clay ring which slips into place

with a bayonet catch. The inverted mantle can be attached to its supporting ring to rather better advantage than the upright mantle, and the mass of the mantle itself being smaller, the whole affair is less liable to fracture from vibration, so that it has been freely used for lighting railway trains with Pintsch gas.

The typical inverted burner, such as is here described, consumes about 3 feet of average good gas per hour and gives between 50 and 55 mean spherical candle power when new, thus doing better in the point of economy than the older type of burner. Inverted burners of larger capacity with larger mantles have come into some use for street lighting, and a smaller type corresponding somewhat to the Welsbach Junior, just referred to, is being developed for interior lighting. The advent of the inverted burner makes it possible to use a mantle gas burner in a position which is sometimes very advantageous and which previously had been the sole prerogative of electric incandescent lamps. In this country larger units than 75 to 100 candle power are generally secured by a duplication of the mantles, forming the so-called gas arc lamps, which are used both indoors and out of doors where a light of several hundred candle power is desired. Fig. 50 shows a five-mantle inverted gas arc intended for outdoor use. This lamp utilizes the ordinary inverted mantles, consuming about 3 feet of gas each per hour and performing at about the same efficiency as the single burners.

The most striking and sensational improvement made in gas practice in recent years has been the use of gas in mantle burners supplied under high pressure. The device is an old one, since for at least ten years pressure machines of various types have been in successful use to a moderate extent for feeding ordinary Welsbachs at enhanced gas pressure. It must not be understood that the gas is carried against the mantle at high pressure, but is fed into the mixing tube in such a way as to draw in an adequate addition of air and thus practically to force the combustion within the burner to a point that cannot be reached when supplying gas at the usual pressure. It is merely a device for securing the intense combustion of a considerable volume of gas within a very small space, thus forcing the mantles to extremely high incandescence.

There have been various modifications of this compressed gas supply plan, in some cases the air being artificially compressed;

and even the use of pure oxygen piped to the gas lamps has been tried. Current practice has settled the pressure at 40 to 60 inches of water. This is obtained by various means. In

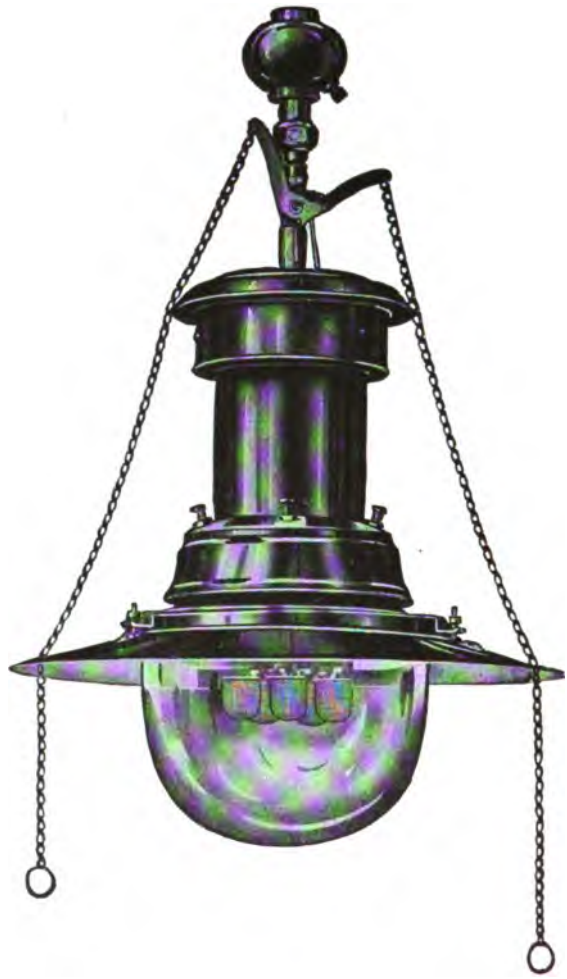


Fig. 50. — Five-mantle Inverted Gas Arc Intended for Outdoor Use.

some cases an automatic blower worked by a rudimentary hot-air engine supplied from the waste heat of the burners has been tried. One form of lamp recently exploited abroad has even gone to the length of working a small electric fan at the bottom of the lamp by

means of current derived from a ring-shaped thermopile operated by the waste heat. As a matter of practice, these individual lamp compressors have found less favor than the somewhat simpler plan of piping the burners for pressure gas supplied from a central compressor station.

In Berlin, which city has the largest example of a press-gas plant, several thousand powerful lamps for the streets are supplied from compressor stations driven by small gas engines and located at convenient points, whence the gas is distributed in Mannesmann steel tubes, at a pressure of 12 centimeters of mercury. The press-gas lamps used on this and similar systems have one or more large Welsbach mantles, the upright ones being some 6 inches in height and the inverted ones of correspondingly large dimensions. They are woven of extra-heavy material, and though owing to the high incandescence the life is much shorter than in the low-pressure mantles, it is said to extend to nearly a month under ordinary conditions of burning. The ordinary press-gas equipments used for street lighting consume from 25 to 35 feet of gas per hour, and give, according to pressure, from 30 to 40 mean spherical candle power per foot of gas. Roughly, therefore, they have more than double the efficiency of the burners worked at ordinary pressure, and give the advantage of a simple and easily maintained large lighting unit well adapted for outside work.

In its evolution press-gas has passed through various stages of pressure, the earlier burners being worked at 8 to 12 inches of water pressure, but later the more general introduction of pressure mains has led to the employment of the higher pressure already referred to. Press-gas lighting has not yet been utilized in this country to any material extent, although some small experimental installations have been set up. The separate piping required involves so considerable an expenditure that it has not appealed to most gas engineers, and at prices current for gas in America the cost of gas, maintenance, and fixed charges have been rather too high to permit competition with electric arcs on a considerable scale. The press-gas lamps, however, are most interesting examples of high efficiency gas lighting and give an admirably steady and powerful light.

In all incandescent gas lamps the vital point is the mantle, and recent improvements have been directed chiefly toward securing

better material and more uniform methods of manufacture. Practically all the ordinary upright mantles manufactured in this country at the present time are made of cotton. Cotton fiber gives a strong mantle, but one that seems to be more subject to deterioration in service than mantles made of some other materials. Abroad, the major part of the mantles, and some of the inverted mantles in this country are made of ramie fiber. This produces a mantle less strong mechanically than a cotton mantle, but comparatively more homogeneous in structure and likely to hold up better.

Within the past two or three years, however, a very radical step has been taken in the substitution of artificial silk as a mantle material for any of the natural fibers. This artificial silk is simply cellulose nitrated in a very moderate degree, substantially in fact collodion gun-cotton. This is inflammable without being explosive, and in manufacture is squirted into very fine threads possessing the luster and almost the flexibility of silk fibers. The material thus produced is wonderfully homogeneous, so that mantles made from it are exceptionally uniform, while also strong and holding up better in candle power than mantles made of natural cellulose. Many of these artificial silk mantles are in use on the Continent, but as yet they have only been manufactured experimentally in this country. The results obtained with them, however, are very encouraging, the artificial cellulose fiber having apparently something of the same advantage in the incandescent gas mantle that it had in the manufacture of the carbon electric incandescent lamp, which went through precisely the same steps of evolution, passing from one natural fiber to another, and finally settling to the structureless artificial cellulose as the most uniform and successful material.

Fig. 51 shows in abstract life curves from three types of mantle, — inverted mantles of ramie fiber and artificial silk, and upright mantles of cotton. It will be noted that the two former hold up wonderfully well, while the latter loses about one-third of its light in a thousand hours. At first thought, it seems singular that the material of the original mantle, which is utterly consumed in the process of manufacture, leaving only a skeleton of the oxides with which the saturated thread is charged, should make so profound a difference in the behavior of the mantle; but the finished mantle, which is merely the ash, partakes in every particular of the

structure of the base on which it was formed, and the cotton gives a less smooth and dense formation, much more liable to shrinkage and breaking away of the finer portions of the structure than does the ramie fiber or the artificial silk.

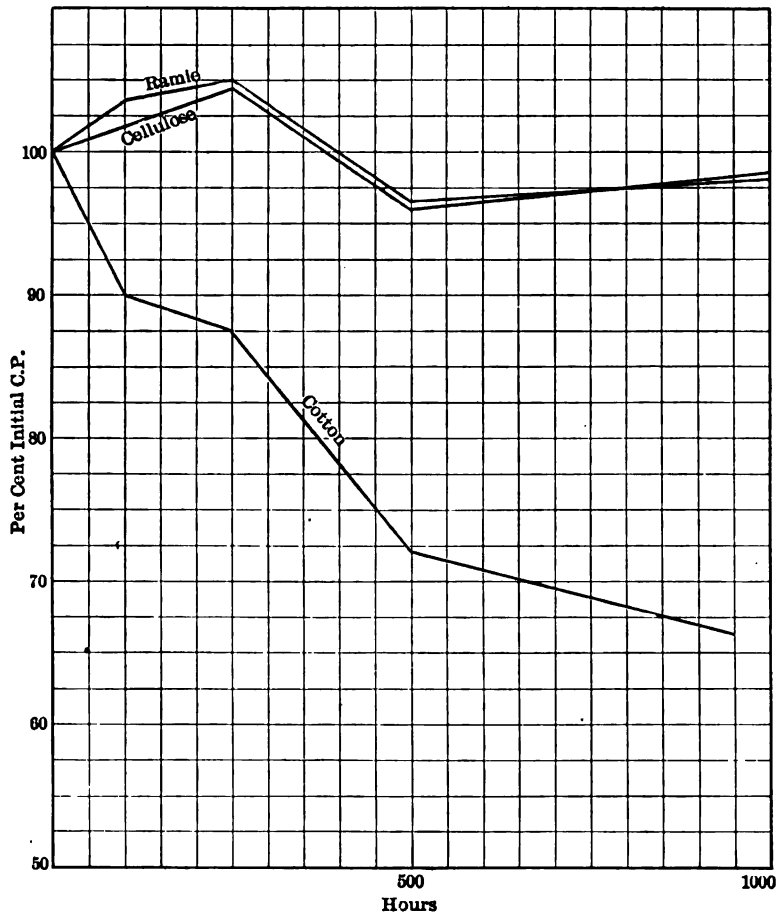


Fig. 51.

It will be noted that the last two give mantles that hold up their candle power almost to the initial point; and in fact in these curves, which are laboratory tests of experimental mantles, actually ran four thousand hours of total life without material depreciation

of candle power. It is hardly probable that the general run of commercial mantles of this material would turn out as well as those here shown, any more than is the case with other commercial products. The results from the cotton mantle are from tests of a considerable group of stock mantles. Nevertheless, the probable improvement in the average quality of mantles by the use of ramie fiber, and particularly of the artificial silk, is very considerable.

Another point in which large modifications have been made in mantle-burner practice is the color. As is familiar to everyone, the ordinary mantle of the past has, after a short period of burning, tended to pass over from a hue fairly near white to one strongly tinged with greenish. A glance at Fig. 46 shows the probable cause of this effect. The less ceria the mantle contains the more the color of the incandescence tends to greenish or bluish; the more ceria, the less the selective radiation in the blue and green and the stronger the light in the yellow and orange. The ceria apparently tends to burn out of the mantle to a certain extent, or at least to lose its activity, so that a mantle starting at one per cent of ceria degenerates after a while to the state of a mantle containing a considerably less percentage, losing in efficiency and acquiring the characteristic greenish tinge. A mantle of composition to give it maximum efficiency is, then, liable to this particular kind of deterioration.

Within the past two or three years a good many mantles containing slightly more ceria have been put out, which give at first a light tending more to the yellow, and, while showing some selective radiation in the green at a later stage, never during their effective life seem to pass to the color of the earlier mantles. Still more recently, further advance has been made in this direction, and mantles are now available giving a very soft yellowish light for a long period of burning. They are, of course, somewhat less efficient than the mantles containing less ceria, but are very much more agreeable in color and hence are better adapted for interior lighting. Mantle manufacture is another of the many cases in which the attempt to get the very highest possible efficiency leads to sacrifice in other directions. These recent types of mantle have not come into very great use as yet, but effectively meet the requirement of furnishing a light "on the yellow" rather than "on the green" in hue.

Ives (Transactions Illuminating Engineering Society, Vol. V, page 208) has given some interesting data on the color variation produced by varying amounts of ceria. The upshot of his figures is that while a mantle containing three-fourths of one per cent of ceria shows rather strong selective radiation in green and bluish green, an increase to 1.25 per cent of ceria makes a radical change in this particular and gives a fair approximation to the hue of the metallic filament electric lamp or the acetylene flame. It is still slightly stronger in the green and slightly weaker in the red than these, but a small additional amount of ceria has been found to even things up in a very satisfactory way. As Fig. 46 shows, the loss in efficiency even for as high as two per cent of ceria is not at all a serious matter. Some space has been devoted to this matter because, while the whole problem has not yet been thoroughly worked out, it is clear that the color difficulty found with the earlier mantle burners can be and has been overcome to a very considerable degree.

The advantage of the mantle burner in steadiness and economy is so great that there would be no reason for using the more common forms of gas burner indoors, except for their occasionally better artistic effects and for their convenience for very small lights. The color question and the fragility of the mantle have been the chief hindrances to the general introduction of the Welsbach type, and these are certainly in large measure avertable.

Recently there have been introduced several forms of mantle burner worked with gas generated on the spot from gasoline or similar petroleum products. Sometimes these are operated as individual lamps and sometimes as small systems to which the gas-forming fluid is piped. They give, of course, a fine, brilliant light, and at a low cost — cheaper than ordinary mantle burners worked with any except rather cheap gas. Where gasoline gas would be cheaper than gas taken from the nearest available main, such gasoline mantle burners will prove economical.

But, as a matter of fact, lamps locally generating and burning their own petroleum gas have been pretty thoroughly tried from time to time during the past twenty-five years, and have never taken a strong or permanent hold on the public. It is therefore difficult to see how mantle burners worked in similar fashion are likely to take a material hold upon the art, although in special

cases they may prove very useful, when illuminating gas is not available at a reasonable price.

It must be constantly borne in mind that the lighter petroleum oils are dangerous and must be used with extreme care, and also that they are likely steadily to rise in price, owing to the increasing use of explosion engines and gas machines.

In using any mantle burner it is good economy to replace the mantle after three or four hundred hours of burning, if it is in regular use to any considerable extent. Of course, in cases when a burner is not regularly used and its maximum brilliancy is not at all needed, the mantle may properly be used until it shows signs of breaking. In other words, as soon as a mantle which is needed at its full efficiency gets dim, throw it promptly away; but so long as it gives plenty of light for its situation, your consumption of gas will not be diminished by a change.

The commonest trouble with mantles is blackening from a deposit of soot owing to temporary derangement of the burner. This deposit can generally be burned off by slightly, not considerably, checking the air supply so as to send up a long, colorless flame which will soon get rid of the carbon, after which the full air supply should be restored. Too great checking of the air supply produces a smoky flame.

It should finally be noted that the mantle burners are particularly useful in cases of troublesome fluctuations in the gas supply, since, while they may burn more or less brightly according to circumstances, they are entirely free from rapid flickering when properly adjusted.

In leaving now the illuminants which depend upon the combustion of a gas or liquid, a brief summation of some of their properties may not come amiss.

The replacement of candles and lamps by gas worked a revolution, not only in the convenience of artificial lighting, but in its hygienic relations. The older illuminants in proportion to their luminous effect removed prodigious amounts of oxygen from the air and gave off large quantities of carbonic acid. In the days of candles a brilliantly lighted room was almost of necessity one in which the air was bad. The following table, due to a well-known authority on hygiene, gives the approximate properties of the common illuminants of combustion as regards their effects on the air of the space in which they are burned:

	Quantity Consumed per Hour.	Candle Power.	Oxygen Removed. Cubic feet.	CO_2 Produced. Cubic feet.	Moisture Produced. Cubic feet.	Heat Produced. Calories.	Vitiation Equal to Adult Persons.
Tallow candles	2200 grains	16	10.7	7.3	8.2	1400	12.0
Sperm candles	1740 "	16	9.6	6.5	6.5	1137	11.0
Paraffin oil	992 "	16	6.2	4.5	3.5	1030	7.5
Kerosene oil	909 "	16	5.9	4.1	3.3	1030	7.0
Coal gas, batwing	5.5 cu. ft.	16	6.5	2.8	7.3	1194	5.0
Coal gas, Argand	4.8 "	16	5.8	2.6	6.4	1240	4.3
Coal gas, regenerative	3.2 "	32	3.6	1.7	4.2	760	2.8
Coal gas, Welsbach	3.5 "	60	4.1	1.8	4.7	763	3.0

To this it may be added that acetylene in these relations is about on a parity with the Welsbach burner, and that oil lamps other than kerosene, burning whale oil, colza oil, etc., would fall in just after candles. It is somewhat startling to realize, but very desirable to remember, that a common gas burner will vitiate the air of a room as much as four or five persons, in so far, at least, as vitiation can be defined by change in the chemical composition of the air.

The introduction of the mantle burner has greatly improved gas lighting from the standpoint of the vitiation of the atmosphere, as a glance at the table will show. For equal light the mantle burner, compared with gas flames, in virtue of its higher efficiency, produces only something like one-fifth the CO_2 and moisture per candle power and removes a similarly small proportion of oxygen. The vitiation of the air with such burners is hardly noticeable, unless they are used in considerable numbers in a limited space. Now and then one notices it in entering a shop brilliantly lighted with mantle burners, but it has disappeared as an important consideration under most circumstances.

In cost also the modern illuminants have a material advantage. In order of diminishing cost the list would run at current American prices of materials about as follows: Candles, animal and vegetable oils, gas in ordinary burners, kerosene, acetylene, Welsbachs, Welsbachs at high pressure.

CHAPTER VII.

THE ELECTRIC INCANDESCENT LAMP.

At the present time the mainstay of electric illumination is the incandescent lamp, in which a filament of high electrical resistance is brought to vivid incandescence by the passage of the electric current. To prevent the rapid oxidation of the incandescent material at the high temperature employed, the filament is mounted in an exhausted glass globe, forming the familiar incandescent lamp of commerce.

The first attempts at incandescent lamps were made with loops or spirals of platinum wire heated by the electric current, either in the air or *in vacuo*, but the results were highly unsatisfactory, since in the open air the wire soon began to disintegrate, and even in the absence of air its life was short. Moreover, the metal itself, being produced in very limited quantities, was expensive at best, and rose very rapidly in price under a small increase of demand. Having a fairly low specific electrical resistance, the wire used had either to be very thin, which made it extremely fragile, or long, which greatly increased its cost per lamp.

Following platinum came carbon in the form of slender pencils mounted *in vacuo*. These, however, were of so low resistance that the current required to heat them was too great to allow of convenient distribution.

To get a practical lamp it was necessary to use a filament of really high resistance, and which was yet strong enough to keep down the cost of replacements.

Without going into the details of the many experiments on incandescent lamps, it is sufficient to say that after much labor the problem of getting a fairly workable filament was solved through the persistent efforts of Edison, Swan, Maxim, Weston, and others, about thirty years ago, the modern art dating from about 1880.

All the carbon filaments are based on the carbonization, out of contact with air, of thin threads of cellulose — the essential constituent of woody fiber. The early work was in the direction

of carbonizing thread in some form, or even paper, but Edison, after an enormous amount of experimenting, settled upon bamboo fiber as the most uniform and enduring material, and the Edison lamp came to the front commercially.

In point of fact, it soon became evident that art could produce a far more uniform carbon filament than nature has provided, so that of late years bamboo, thread, paper, and the rest have been abandoned, and all filaments, save those for some special lamps, are made from soluble cellulose squirted into threads, hardened, carbonized, and "treated."

Fig. 52 shows a typical modern incandescent lamp. It consists essentially of four parts: the base adapted to carry the lamp in its socket, the bulb, the filament, and the filament mounting, which includes the leading-in wires. In its original form the bulb has an opening at each end, one at the base end through which the filament and its mounting are put in place, and another in the form of a narrow tube a few inches long, which when sealed off produces the tip at the end of the bulb.

The filament is made in slightly different ways in different factories, and the exact details of the process, constantly subject to slight improvements, are unnecessary here to be described. Substantially it is as follows: The basis of operations is the purest cellulose convenient to obtain, filter paper and the finest absorbent cotton being common starting points. The material is pulped, as in paper making, dissolved in some suitable substance, zinc-chloride solution being one of those used, evaporated to about the consistency of thick molasses, and then squirted under air pressure into a fine thread, which is received in an alcohol bath to harden it.

Thus squirted through a die, the filament is of very uniform constitution and size, and after carbonization out of contact with air it forms a carbon thread that is wonderfully flexible and strong. But even so, there is not yet a perfectly uniform filament, and the carbon is not dense and homogeneous enough to stand protracted incandescence.

On passage of current portions of the filament may show too low resistance, so as to be dull, or too high resistance, so as to get too hot and burn off. It is hard, too, to produce a durable filament of the somewhat porous carbon obtained in the way described.

In making up the filaments they are, therefore, subjected prior to being sealed into the lamp to what is known as the flashing

process. This has a twofold object, — to build up the filament with dense carbon and to correct any lack of uniformity which may exist. The latter purpose is far less important to the squirted

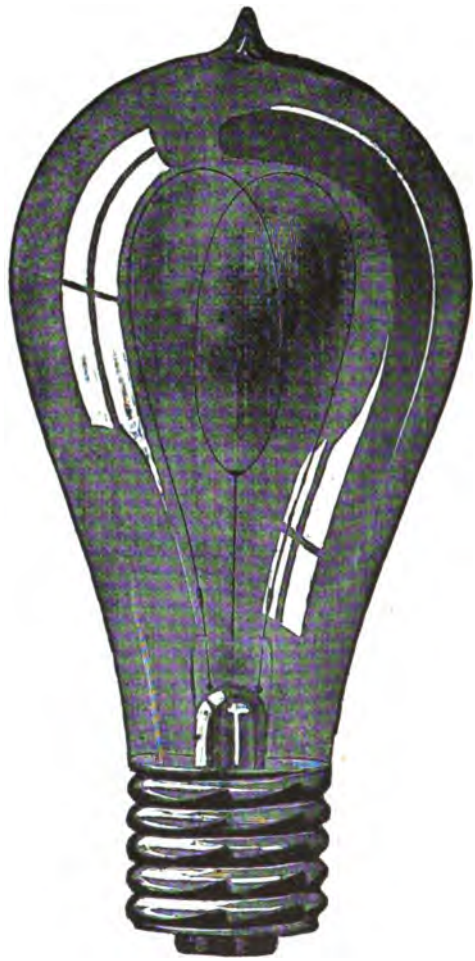


Fig. 52. — Typical Incandescent Lamp.

filaments than to the old filaments of bamboo fiber or thread, but the former is important in securing a uniform product. The filaments are mounted and then are gradually brought to vivid incandescence in an atmosphere of hydrocarbon vapor, produced from gasoline or the like.

The heated surface decomposes the vapor, and the carbon is deposited upon the filament in the form of a smooth, uniform coating almost as dense as graphite, and a considerably better conductor than the original filament. If, as in the early bamboo filaments, there are any spots of poorer conductivity or smaller cross section than is proper, these become hot first and are built up toward uniformity as the current is gradually raised, so that the filament is automatically made uniform.

The flashing process is actually quick, the gradual rise of current being really measured by seconds. With the squirted filaments now used the main value of the flashing process is to enable the conductivity of the filament to be quite accurately regulated, at the same time giving it a firm, hard coating of carbon that greatly increases its durability. The finished filaments are strong and elastic, generally a fine steely gray in color, with a polished surface, and for lamps of ordinary candle power and voltage vary from 6 to 12 inches in length, with a diameter of 5 to 10 one-thousandths of an inch.

The filaments are joined near the base of the lamp to two short bits of thin platinum wire which are sealed through one end of a short piece of glass tube. Sometimes these platinum leading-in wires are fastened directly to the ends of the filament and sometimes to an intermediary terminal of copper wire attached to the filament. Within the tube the platinum wires are welded to the copper leads which pass down the mounting tube and are attached to the base. The filament itself is cemented to its copper or platinum wires by means of a little drop of carbon paste.

No effective substitute for platinum in sealing through the glass has yet been found, although many have been tried. Platinum and glass have very nearly the same coefficient of expansion with heat, so that the seal remains tight at all temperatures without breaking away. It is possible to find alloys with nearly the right coefficient of expansion, but they have generally proved unsatisfactory either mechanically or electrically, so that the line of improvement has mainly been in the direction of making a very short seal with platinum wires.

The filament thus mounted is secured in the bulb by sealing the base of the mounting tube or lamp stem into the base of the bulb. This leaves the bulb closed except for the exhaustion tube at its tip.

The next step is the exhaustion of the bulb. This used to be done almost entirely by mercury pumps, and great pains was taken to secure a very high degree of exhaustion. It was soon found that there was such a thing as too high exhaustion, but the degree found to be commercially desirable is still beyond the easy capabilities of mechanical air pumps, at least for regular and uniform commercial practice, although they have been sometimes successfully used.

At the present time the slow though effective mercury pump is being to a very large extent superseded by the Malignani process, or modifications thereof. The bulbs are rapidly exhausted by mechanical air pumps, and when these have reached the convenient limit of their action the residual gas is chemically absorbed by the vapor produced by heating a small quantity of amorphous phosphorus previously placed in a tubulaire connected with the exhaustion tube. The process is cheap, rapid, and effective, and with a little practice the operator can produce exhaustion that is almost absolutely uniform.

Whatever be the method of exhaustion, during its later stages current is put on the filaments both to heat them, and thus to drive out the occluded gases, and to serve as an index of the exhaustion. When exhaustion is complete the leading-in tube is quickly sealed off, and the lamp is done, save for cementing on the base and attaching it to the leads that come from the seal. After this the lamps are sorted, tested, and made ready for the market.

The shape of the filament in the lamp was originally a simple U, later often modified to a U with a quarter twist so that the plane of the loop at the top was 90 degrees from its plane at the base. As the voltage of distribution has steadily crept upwards from 100 to 110, 120, 140, and even 250 volts, it has been necessary either to increase the specific resistance of the filament, to decrease its diameter, or to increase its length, in order to get the necessary resistance to keep the total energy, and likewise the temperature of the filament, down to the desired point.

But the modern flashed filament cannot be greatly increased in specific resistance without impairing its stability, so the filaments have been growing steadily finer and longer. At present their form is various, according to the judgment of the maker in stowing away the necessary amount of filament within the bulb.

One very common form is that of Fig. 52, where the filament has a single long convolution anchored to the base at its middle point for mechanical steadiness. Sometimes there are two convolutions, or even more, and sometimes there is merely a reduplication of the old-fashioned simple loop, as in Fig. 53.

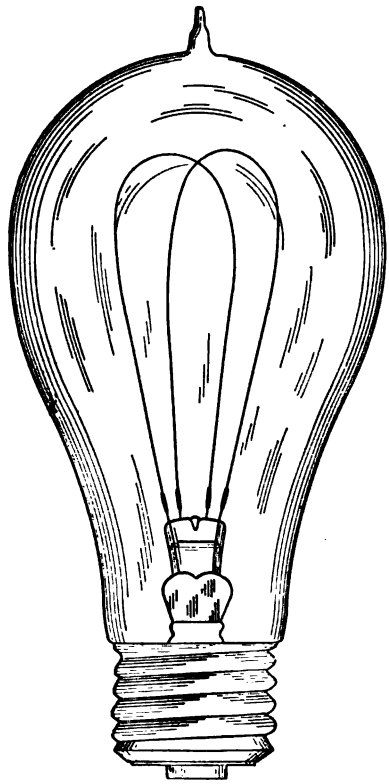


Fig. 53. — Lamp with Double Filament.

The section of the filaments is now always circular, although in the early lamps it was sometimes rectangular or square.

There has been a considerable fog of mystery about incandescent lamp manufacture, for commercial purposes, but the general facts are very firmly established and by no means complicated, and a little consideration of them will clear up much of the haze.

To begin with, it is not difficult to make a good filament, but it takes much skill and practice to produce, in quantity, one that

shall be uniformly good. The quality of the lamps as to durability and other essentials depends very largely on the care and conscientiousness of the maker in sorting and rating his product.

It is practically impossible, for example, to make, say, 10,000 filaments, all of which shall give 15 to 17 horizontal candle power at a particular voltage, say 110. With great skill in manufacture, half or rather more will fall within these limits, the rest requiring anywhere between 100 and 120 volts to give that candle power. Only a few will reach these extremes, the rest being clustered more or less closely around the central point.

The value of the lamps as sold depends largely on what is done with the varying ones and how carefully they are sorted and rated. If the lamps demanded on the market were all of 110 volts, then there would be a large by-product which would either have to be thrown away, sold for odd lamps of uncertain properties, or slipped surreptitiously into lots of standard lamps.

But some companies use lamps of 108 or 112, or some neighboring voltage, and part of the product is therefore exactly fitted to their needs, and so forth, there being involved only some slight gain or loss in efficiency, not important if similar lamps from other lots are conscientiously rated along with them.

The basic facts in incandescent lamp practice are two: First, the efficiency, i.e., the ratio of energy consumed to light given per unit of surface, depends mainly on the temperature to which the filament is carried; second, the total light given is directly proportional to the filament surface which radiates this light. The specific radiating power of modern carbon filaments is substantially uniform, so that if one has two filaments of the same surface brought to the same temperature of incandescence, they will work at substantially the same efficiency and give substantially the same amount of light.

And if a filament of a certain surface be brought to a certain temperature, it will give a definite total amount of light, utterly irrespective of the form in which the filament is disposed. Changes in the form of the filament will produce changes in the distribution of the light in different directions around the lamp, but will not in the least change the total luminous radiation. Much of the current misunderstanding is due to neglect of this simple fact.

The nominal candle power of the lamp depends upon a pure convention as to the direction and manner in which the light shall

be measured in rating the lamp, and makers have often sought to beat the game by disposing the filament so as to exaggerate the radiation in the conventional direction of measurement.

For example: Many early incandescent lamps had filaments of square cross section bent into a single simple U. These gave their rated candle power in directions horizontally 45 degrees from the plane of the filaments, and this was the maximum in any direction, so that the lamp when thus measured was really credited with its maximum candle power, and fell below its rating in all directions save the four horizontal directions just noted.

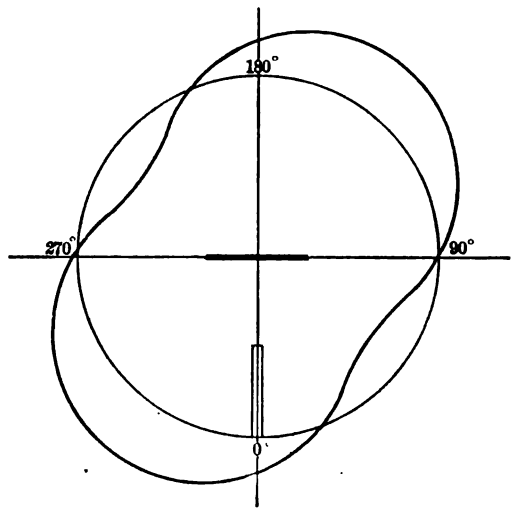


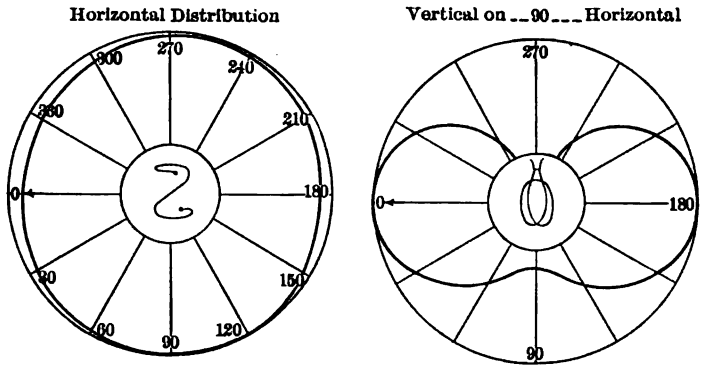
Fig. 54. — Distribution of Light from Flat Filament.

It is customary to delineate the light from an incandescent lamp in the form of closed curves, of which the various radii represent in direction and length the relative candle power in those various directions. Such curves may be made to show accurately the distribution of light in a horizontal plane about the lamp, or the distribution in any vertical plane, and from the average radii in any plane may be deduced the mean candle power in that plane, while from a combination of the radii in the various planes may be obtained the mean spherical candle power which measures the total luminous radiation in all directions.

This last is the true measure of the total light-giving power of a lamp. Fig. 54 illustrates the curve of horizontal distribution for

one of the early lamps, having a flat U-shaped filament. The circle is drawn to show a uniform 16 candle power, while the irregular curve shows the actual horizontal distribution of light. This particular lamp overran its rating, but its main characteristic is that it gave a strong light in one horizontal diameter and a weak one in the diameter at right angles to this.

Such a distribution as this is generally objectionable, and most modern filaments are twisted or looped, so that the horizontal distribution is nearly circular. Fig. 55 shows a similar curve for a recent 16-c.p. lamp of the type shown in Fig. 52. In the small inner circle is shown the projection of the looped filament as one looks down upon the top of the lamp. Fig. 56 shows a similar



Figs. 55 and 56. — Distribution of Light from Looped Filament.

delineation of the distribution of light in a vertical plane taken in the azimuth shown in Fig. 55, with the socket up.

The looping of the filament is such that the horizontal distribution is very uniform, while in the vertical downwards there is a marked diminution of light, and of course in the direction of the socket most of the light is cut off. The total spherical distribution, if one can conceive it laid out in space in three dimensions, resembles a very flat apple with a marked depression at the blossom end and a cusp clear into the center at the stem end. Fig. 57 is an attempt to display this spherical distribution to the eye.

If the filament were a simple U, or the double U of Fig. 53, assuming the same total length and temperature of filament, the apple would have still greater diameter, but the depression at the blossom end would be considerably wider and deeper.

If the filament has several convolutions, as in Fig. 58, this depression is considerably reduced, but there is a marked flattening in one horizontal direction, so that the horizontal distribution would somewhat resemble Fig. 54. But the total luminous radiation would be quite unchanged.

If the lamps were rated by their mean horizontal candle power, the U filament would show abnormally large horizontal illumination for the energy consumed, and would apparently be very efficient, while if one were foolish enough to rate lamps by the

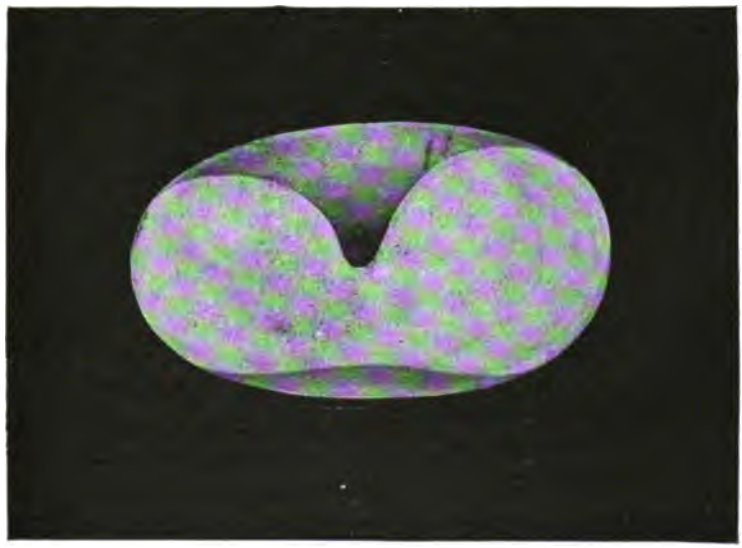


Fig. 57. — Distribution of Light from Incandescent Lamp.

light given off the tip alone, Fig. 58 would show great efficiency, the distribution in one horizontal diameter having been reduced to fatten the curve at the tip. In reality, however, each one of the three forms of lamp would have exactly the same efficiency, and in practice there would be little choice between them.

In the everyday work of illumination carbon incandescent lamps are installed with their axes in every possible direction, the vertical being the rarest, and angles between 30 degrees and 60 degrees downwards from the horizontal the commonest.

Bearing in mind this general distribution of the axes and the fact that diffusion goes very far toward obliterating differences in

the spherical distribution as regards general illumination, it is easy to see that the shape of the filament is, for practical purposes of illumination, of little account. In the few cases where directed illumination is needed it is best secured by a proper reflector, which gives far better results than can be obtained by juggling with the shape of the filament.

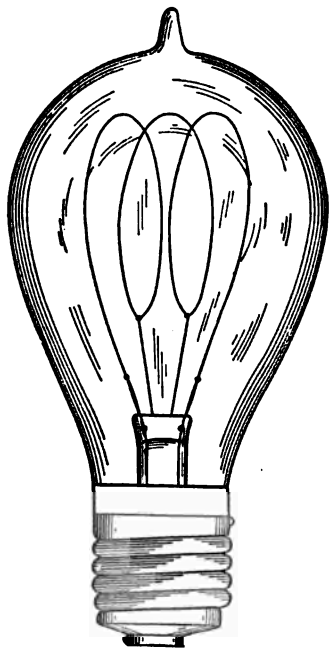


Fig. 58. — Lamp with Multiple-looped Filament.

The thing of importance is to get uniform filaments of first-class durability, and of as good efficiency as possible. The only proper test for efficiency, however, is that based on mean spherical candle power, since a lamp will give a different apparent efficiency for each direction of measurement, varying from zero in the direction of the socket to a maximum in some direction unknown until found.

Efficiency has most often been taken with respect to the mean horizontal candle power. But this leads to correct relative results only when comparing lamps having filaments similarly curved. The mean spherical candle power is usually from 80 to 85 per cent of the mean horizontal candle power.

As regards efficiency, most commercial incandescent lamps require between 3 and 4 watts per mean horizontal candle power. Now and then lamps are worked at 2.5 watts per candle when used with storage batteries, and some special lamps, especially some of those made for voltages above 200, range over 4 watts per candle. As has already been remarked, the efficiency depends upon the temperature at which the carbon filament is worked. And it is in the ability to stand protracted high temperature that filaments vary most.

It is comparatively easy to make a filament which will stand up well when worked at 4 watts per candle, but to make a good 3-watt-per-candle filament is a very different proposition. Also,

at low voltage, 50 volts for instance, the filament is more substantial than the far slenderer one necessary to give the requisite resistance for use at the same candle power at 100 or 125 volts.

Under protracted use the filament loses substance by slow disintegration and by a process akin to evaporation, so that the surface changes its appearance, the resistance increases so that less current flows, the efficiency consequently falls off, and the globe shows more or less blackening from an internal deposit of carbon.

The thinner and hotter the filament the less its endurance and the sooner it deteriorates or actually breaks down. Modern carbon lamps have by improved methods of manufacture been developed to a point that in the early days of incandescent lighting would have seemed beyond hope of reach. But the working voltage has steadily risen and constantly increased the difficulties of the manufacturer.

So-called high-efficiency lamps worked at about 3 watts per candle power require the temperature of the filament to be carried so high that its life is seriously endangered unless it be of fair diameter; hence such lamps are hard to make for low candle power or for high voltage, either of which conditions requires a slender filament — in the former case to limit the radiant surface, in the latter to get in the needful resistance. An 8-c.p. 125-volt lamp, or a 16-c.p. 250-volt lamp, presents serious difficulties if the efficiency must be high, while lamps of 24 or 32 candle power are far more easily made for high voltage.

The annexed table gives a clear idea of the performance of a carbon filament lamp under various conditions of working. It is from tests made on a 16-c.p. 100-volt lamp (so-called) by Prof. H. J. Weber.

Amperes.	Volts.	Watts.	Candle Power.	Watts per Candle Power.	Temperature.
0.421	77.19	32.51	2.99	10.87	1464° C.
0.443	80.89	35.85	4.13	8.67	1483
0.467	84.80	39.58	5.60	7.07	1503
0.490	88.83	43.55	7.41	5.88	1522
0.513	92.87	47.70	9.71	4.91	1541
0.536	96.71	51.84	12.42	4.18	1557
0.559	100.60	56.21	15.76	3.57	1574
0.582	104.58	60.90	19.70	3.09	1591
0.605	108.60	65.78	24.25	2.71	1607
0.629	112.57	70.85	29.41	2.41	1621

The absolute values of the temperatures here given are the least exact part of the table, but the relative values may be trusted to a close approximation. More recent data indicate that the true filament temperatures range from about 1800° C. in a 4-watt-per-candle lamp to nearly 1950 degrees at 3.1 watts per candle. Fig. 59 shows in graphical form the relation between the last two columns, showing clearly how conspicuously the efficiency rises with the temperature. At the upper limit given the carbon is too hot to give a long life, although the writer has seen modern lamps worked 12 volts above their rating for several hundred hours before rapid breakage began. Of course the brilliancy had fallen off greatly by that time.

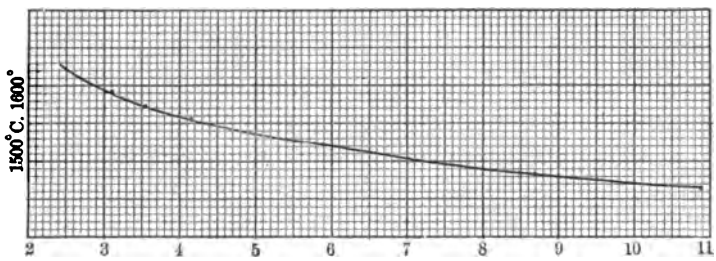


Fig. 59. — Variation of Efficiency with Temperature.

It is worth noting from the table that for a 16-c.p. lamp of ordinary voltage the candle power varies to the extent of quite nearly one candle power per volt, for moderate changes of voltage from the normal. Weber calls attention to the fact that between 1400 degrees and 1650 degrees an increase in temperature of n degrees corresponds very closely to a saving in energy of n per cent in the production of light.

If it were possible to carry the temperature still higher without seriously impairing the stability of the filament, lamps of a very high economy could be produced. It is possible to force lamps up to an economy of even 1.5 watts per candle temporarily, but they often break almost at once, and even if they hold together they rise to 2 or 2.5 watts per candle within a few hours.

To tell the truth, the temperature corresponding to 1.5 watts per candle is dangerously near the vaporizing point of the material, — so near that it is practically hopeless to expect any approximation to such efficiency from carbon filaments, and even at 2.5 watts per

candle the life of the lamps is so short that at present prices they cannot be used commercially.

From such experiments as those tabulated it has been shown that the relation between the luminous intensity and the energy expended in an incandescent lamp may be expressed quite nearly by the following formula:

$$I = aW^3,$$

wherein I is the candle power, W the watts used, and a is a quantity approximately constant for a given type of lamp, but varying slightly from type to type.

Following the universal rule of incandescent bodies, the radiation from an incandescent lamp varies in color with the temperature, and thus as the voltage changes, or what is about the same thing, as lamps of different efficiencies are used, the color of the light varies very conspicuously. Low efficiency lamps, or lamps in a low stage of incandescence, such as is indicated in the first four lines of the table, burn distinctly red or reddish orange. Then the incandescence passes through the various stages of orange-yellow and yellow until a 3-watt lamp is clear yellowish white and a 2.5-watt lamp still more whitish. The color is a good index of the efficiency.

The sizes of carbon incandescent lamps in common use are 8, 10, 16, 20, 24, and 32 candle power. The standard in this country is the 16-c.p. size, a figure borrowed from the legal requirements for gas. Some 10 candle power lamps are used here, very few 8 candle power, and still fewer of candle powers above 16. Abroad, 8-c.p. lamps are used in great numbers and with excellent results. The 20-c.p. and 24-c.p. lamps are found mostly in high voltages, for reasons that will appear shortly. Two-, 4-, and 6-c.p. lamps are considerably used for decorative purposes or for night-lights, and excellent 50-c.p. lamps are available for cases requiring radiants of unusual power.

Lamps of these various sizes are made usually for voltages between 100 and 120 volts, and more rarely for 220 to 250 volts, but in the latter case lamps below 16 candle power are used in America only to a very small extent.

In lamps of small candle power or of high voltage there is some temptation to get resistance by flashing the filaments less thoroughly, to the detriment of durability, since the soft core dis-

integrates more readily than the hard deposited carbon, which may explain the frequent inferiority of such lamps. The greater the candle power, and the less efficiency required, i.e., the greater the permissible radiating surface, the easier it is to get a strong and durable filament for high voltages. Hence, lamps for 220 to 250 volts are generally of at least 16 candle power, very often of 20 or 24 candle power, and seldom show an efficiency better than 4 watts per candle power.

This forms a serious practical objection to the use of such lamps for general distribution, unless with cheap water power as the source of energy, and while improved methods of manufacture are likely somewhat to better these conditions, yet there are inherent reasons why it should be materially easier to produce durable and efficient incandescent lamps of moderate candle power and voltage than lamps of extreme properties in either of these directions.

If the lamp is started at a low efficiency, the temperature is relatively low and the decadence of the filament is retarded, while if the lamp is initially of high efficiency the filament under the higher temperature deteriorates more rapidly and the useful life of the lamp is shortened.

Under this latter condition the cost of energy to run the lamp is diminished, but at the price of increased expense in lamp renewals. Operating at low efficiency means considerable cost for energy and low cost of the lamp renewals. Between these divergent factors an economic balance has to be struck.

It is neither desirable nor economical to operate an incandescent lamp too long, since not only does it decrease greatly in efficiency, but the actual light is so dimmed that the service becomes poor. If the lighting of a room is planned for the use of 16-c.p. lamps, and they are used until the candle power falls to, say, 10, which would be in about 600 hours in an ordinary 3-watt-per-candle lamp, the resulting illumination would be altogether unsatisfactory. Quite aside from any consideration of efficiency, therefore, it becomes desirable to throw away lamps of which the candle power has fallen below a certain point.

Much of the skill in modern lamp manufacture is directed to securing the best possible balance between efficiency and useful life, a thing requiring the most painstaking efforts of the manufacturer. Fig. 60 shows graphically the relation between life, candle power, and watts per candle derived from tests of high-

grade foreign carbon lamps. In comparing these, like the previous data, with American results, it should be borne in mind that these foreign tests are made, not in terms of the English standard candle, but generally in terms of the Hefner-Alteneck standard, which is somewhat (approximately 10 per cent) smaller.

These curves show the results from lamps having an initial efficiency of 2.5, 3.0, and 3.5 watts per candle power and an initial candle power of 16. They show plainly the effect of increased temperature on the life of the lamp, and it is unpleasantly evident that in the neighborhood of 3 watts per candle a point is reached at which a further increase of efficiency produces a disastrous result

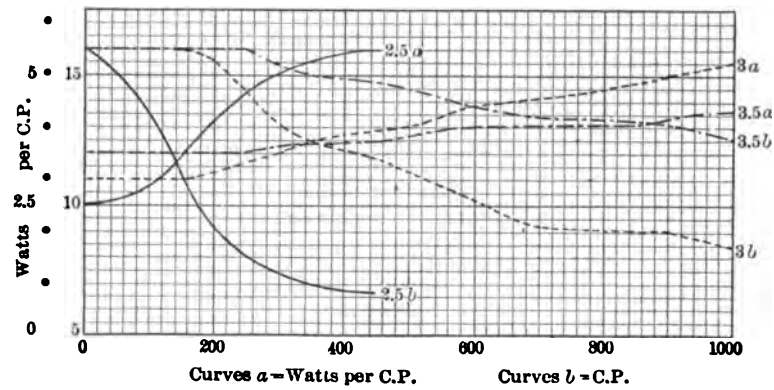


Fig. 60. — Curves Showing Life, Candle Power, and Watts per Candle.

upon the life; in other words, such efficiency requires a temperature at which the carbon filament rapidly breaks down.

And so long as carbon is used as the radiant material there is a strong probability that there can be no very radical improvement in efficiency. Of course, if incandescent lamps were greatly cheapened, it would pay to burn them at higher efficiency and to replace them oftener.

In production on a large scale the mere manufacture of the lamps can be done very cheaply, probably at a cost not exceeding 7 to 8 cents, but the cost of proper sorting and testing to turn out a uniform high-grade lamp, and the incidental losses from breakage and from lamps of odd and unsalable voltages, raise the total cost of production very materially. Much of the reduction in the price of incandescent lamps in the past few years has resulted

from better conditions in these latter respects, as well as from the improved methods of manufacture.

And it should be pointed out that the difference between good and bad lamps, as practically found upon the market, lies mostly in their different rates of decay of light and efficiency. It is the practice of many of the large lighting companies who renew the lamps for which they furnish current to reject and replace lamps which have fallen to about 80 per cent of their initial power.

First-class modern lamps worked in the vicinity of 3 watts per candle power will hold up for 400 to 450 hours before falling below this limit, and at 3.5 or 3.6 watts per candle power will endure nearly double that time. They are often rated in candle-hours of effective life, and on the showing just noted the recent high-efficiency lamp will give a useful life of 6000 to 7000 candle-hours, with an average economy of perhaps 3.25 watts per candle. A medium-grade lamp of similar nominal efficiency may not show with a similar consumption of energy more than 250 or 300 hours of effective life — say 4000 to 4500 candle-hours.

The economics of the matter appear as follows: The first lamp during its useful life of, say, 6500 candle-hours, will consume 21.125 kilowatt hours, costing at, say, 15 cents per kilowatt hour, $3.17, and adding the lamp at 18 cents, the total cost is $3.35, or 0.0515 cent per candle-hour, while the poorer lamp at 4000 candle-hours will use $1.95 worth of energy, and at 18 cents for the lamp would cost 0.0532 cent per candle-hour. To bring the two lamps to equality of total cost, irrespective of the labor of renewals, the poorer one would have to be purchased at 11 cents. In other words, poor lamps, if discarded when they should be, generally so increase the cost of renewals that it does not pay to use them at any price at which they can be purchased under ordinary circumstances.

As has already been explained, lamps deteriorate very rapidly if exposed to abnormal voltage, and the higher the temperature at which the lamp is normally worked the more deadly is the effect of increased voltage. It thus comes about that if high-efficiency lamps are to be used, very good regulation is necessary. Occasional exposure to a 5 per cent increase of voltage may easily halve the useful life of a lamp, while, of course, permanent working at such an increase would play havoc with the life, cutting it down to 20 per cent or less of the normal. Good regulation is,

therefore, of very great importance in incandescent lighting, not only to save the lamps and to improve the service, but to render feasible the use of high-efficiency lamps. On the whole, the best average results seem to be obtained in working lamps at 3 to 3.5 watts per candle. Those of higher efficiency fail so rapidly that it only pays to use them when energy is very expensive and must be economized to the utmost. The 2.5-watt lamp of Fig. 60, for example, has an effective life of not more than 150 hours, at an average efficiency of about 2.75 watts per candle. A 2-watt lamp will fall to 80 per cent of its original candle power in not far from 30 hours, at an average efficiency of about 2.25 watts; while if started as a 1.5-watt lamp, in a few hours the filament is reduced to practical uselessness.

There is seldom any occasion to use lamps requiring more than 3.5 watts per candle power, save in case of very high voltage installations, where the saving in cost of distribution may offset the cost of the added energy. The difficulty of making durable 250-volt lamps on account of the extreme thinness of the filament has been already referred to, and it is certainly advisable to use in such installations lamps of 20 candle power or more whenever possible, thus making it practicable to work at better efficiency without increased risk of breakage. Even when power is very cheap there is no object in wasting it, and a little care will generally secure regulation good enough to justify the employment of incandescent lamps of good efficiency.

Further, in the commercial use of lamps it is necessary for economy that the product should be uniform. It has already been shown that medium-grade lamps are characterized by a shorter useful life than first-class lamps. Unfortunately, there are on the market much worse lamps than those described. It is not difficult to find lamps in quantity that are so poor as to fall to 80 per cent of their initial power in less than 100 hours. A brief computation of the cost of replacement will show that these are dear at any price. Now, if lamps are not carefully sorted, a given lot will contain both good lamps and poor lamps, and will not only show a decreased average value, but will contain many individual lamps so bad as to give very poor and uneconomical service. Fig. 61 shows what is sometimes known as a "shotgun diagram," illustrating the variations found in carelessly sorted commercial lamps. In this case the specifications called

for 16-c.p., 3.5-watt-per-candle lamps. The variation permitted was from 14.5 to 17.5 mean horizontal candle power, and from 53 to 59 total watts, which is a liberal allowance, some companies demanding a decidedly closer adherence to the specified limits.

The area defined by these limits is marked off in the cut, forming the central "target." The real measurements of the lamps tested are then plotted on the diagram and the briefest inspection

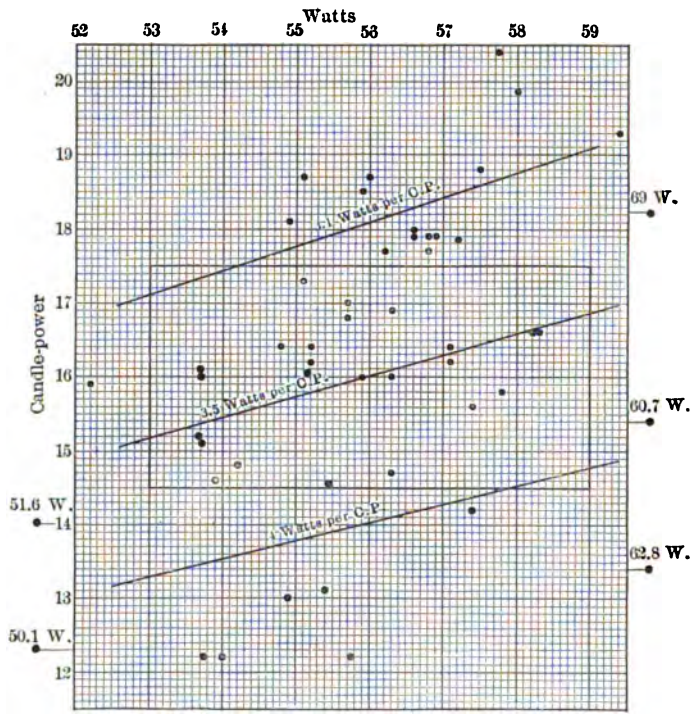


Fig. 61. — Shotgun Diagram.

shows the results. In this case only 46 per cent of the lamps hit the specifications. All lamps above the upper slanting line are below 3.1 watts per candle power, and hence are likely to give trouble by falling rapidly in brilliancy and breaking early. Lamps below the lower slanting line are over 4 watts per candle power, hence are undesirably inefficient. Moreover, the initial candle power of the lot varies from 12.2 candle power to 20.4 candle power.

Such a lot will necessarily give poorer service and less satisfactory life, and is, as a matter of dollars and cents, worth much less to the user than if the lamps had been properly sorted at the factory. Filaments cannot be made exactly alike, and the manufacturer has to rely upon intelligent sorting to make use of the product. For example, the topmost lamp of Fig. 61 should have been marked for a lower voltage, at which it would have done well. Nearly all the lot would have properly fallen within commercial specifications for 16-c.p. lamps at some practicable voltage and rating in watts per candle power. The imperfect sorting has misplaced many of the lamps and depreciated the whole lot.

In commercial practice lamps should be carefully sorted to meet the required specifications, and the persons who buy lamps should insist upon rigid adherence to the specifications, and should, in buying large quantities, test them to insure their correctness. To sum up, it pays to use good lamps of as high efficiency as is compatible with proper life, and to see that one gets them.

The real efficiency of an incandescent lamp, i.e., the proportion of the total energy supplied which appears as visible luminous energy, is very small, ordinarily from 2 to 3 per cent in carbon lamps, not over 5 to 6 per cent even in the best metallic filament lamps. This means that in working incandescent lamps from steam-driven plants less than 0.5 per cent of the energy of the coal appears as useful light.

Up to about 1905 the carbon lamp substantially as just described was the only form of incandescent lamp used in this country. At about this time a radical modification in carbon filaments was produced which has come into large commercial use. This was the so-called metallized filament, substantially an allotropic form of carbon which was the result of attempts to convert an ordinary carbon filament into pure graphitic carbon. The manufacture of the metallized filament starts with the ordinary squirted cellulose filament already described as the base of operations. This is baked in an electric furnace at a very high temperature, and after subjection to a flashing process akin to that in general use is again fired, the temperature being carried to the neighborhood of 3000° C. The result is a complete change in the texture and appearance of the carbon and in its physical proper-

ties. The specific resistance is enormously reduced, falling to a figure comparable with the poorly conducting metals, and the temperature coefficient becomes positive like that of a metal, instead of being negative, as in the ordinary forms of carbon. The metallized filament in practice has only a very small temperature coefficient of either sign, and is, from its lower resistance, much slenderer than the ordinary carbon filament and considerably more refractory, so that it can be worked at a higher temperature.

The normal initial specific consumption of these lamps is about 2.5 watts per m. h. c. p., and the life and fall of candle power during life approximately the same as for the 3.1-watt ordinary carbon-filament lamps. Such lamps are manufactured in sizes of 50, 100, 125, 187, and 250 watts, rated respectively at 20, 40, 50, 75, and 100 candle power. The smallest size has replaced the ordinary 50-watt 16-c.p. carbon lamp to a very large extent, and the larger sizes have been considerably used in commercial lighting, but are now rapidly disappearing under the competition of the true metallic filament lamps.

The metallized filament, interesting as it is, was an improvement introduced a few years too late, since at the time of its production the true metallic filament lamps, now coming into general use, had already been produced abroad. The metallized filament lamps, therefore, which resemble in general properties and distribution of light the carbon lamps which had preceded them, are now only of passing interest. The first of the metallic filament group of lamps was the osmium lamp of Dr. Auer von Welsbach. Osmium is a rare metal found associated with the platinum group in small quantities. It has an atomic weight of 191, a specific gravity of 22.48, and a specific resistance in the lamp filaments of about 47 microhms per cubic centimeter. It is a strong acid-forming element of extremely uncompromising mechanical qualities, and has not yet been produced in true metallic form, but only as a black powder. The osmium filaments were made by mixing the finely divided metal with a binding material into a paste, squirting it through dies into a filament, and then driving out the binder by intense heat and sintering the residuum into a coherent metallic mass. The relatively high conductivity of the metal forbade the successful production of filaments for ordinary voltages, and most of the commercial lamps were intended to be burned at a pressure of about 50 volts, either on a separate circuit, or two in series on

the ordinary voltages. Even so, the ordinary lamp of about 20 candle power contained 3 loops in series, each about 2.5 inches long and anchored near the tip of the lamp. The filaments when hot were so plastic that the lamp had to be burned tip down.

The specific consumption of the osmium lamp, however, was so low, from 1 to 1.5 watts per candle, that in spite of the difficulties of fragility and high cost it came into commercial use on a modest scale, and its success was the immediate cause of the further researches which led to the development of the metallic filament lamps now in common use. The most serious difficulty with the osmium as a material for filaments, however, was the extreme rarity of the metal, so that if it had been employed to any considerable extent the price must inevitably have risen very seriously. As it was, the difficulty was felt to an extent which was met by putting out the lamps on a nominal lease so as to insure their return and the saving of the material. The osmium lamp is now only of historical interest, but its production was of the greatest importance to the industry in stimulating further improvements.

The first really successful metallic filament lamp in a large commercial way was the tantalum lamp now used in large quantities. Tantalum is another of the relatively rare metals, of atomic weight 183, density about 16.8, and specific resistance about 16.5 microhms per cubic centimeter. As prepared in the electric furnace, it is a whitish, intensely hard metal, with about the strength of steel, not attacked by any of the ordinary acids, and with a melting point considerably higher than that of platinum. It is sufficiently ductile to be drawn into very fine wire, which for use in lamps is commonly about 2 mils in diameter, of which about 2 feet is necessary to produce a commercial 110-volt lamp of 20 to 25 candle power.

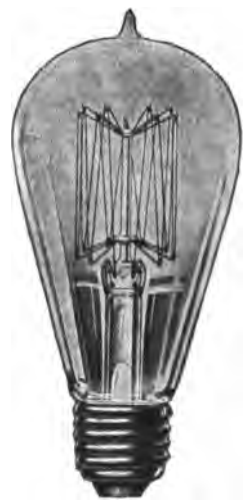


Fig. 62. — Tantalum Lamp.

On account of the great length of filament to be supported, it has to be strung on supporting spiders in 10 or more short loops. Fig. 62 shows the ordinary commercial tantalum lamp as manufactured in this country. The tantalum lamp is ordinarily worked at a specific efficiency of 2 watts per candle.

At this efficiency its normal life before falling off, say 20 per cent in candle power, is in the neighborhood of 800 hours, although individual lamps will often burn considerably longer than this without reaching the loss specified. After protracted use the filament tends to draw tight over the spiders and eventually breaks. The filament, however, possesses a curious capacity for easy welding, so that a broken lamp may often be connected with the circuit and manipulated so as to weld a broken length of filament to the next stretch, sometimes with a very trivial loss in length, after which the lamp may burn for several hundred hours more, and perhaps be again rewelded if one follows the operation to its limit.

The most serious fault of the tantalum filament is its inability to give good results on alternating-current circuits. When burned upon these the filament tends to break crosswise and weld itself together again without actually separating, so that when examined under the microscope the filament looks as though it had been many times broken and carelessly glued together again. Fig. 63 shows a photomicrograph of a filament thus affected. After a couple of hundred hours burning on an ordinary 60-cycle circuit this "faulting" has occurred to such an extent that the filament is very fragile. Its life on such a circuit is approximately half that on direct current, although individual lamps may occasionally last 1000 hours or more. The cause of this "faulting" has never been ferreted out, nor has it as yet been remedied. The beautiful mechanical properties of the tantalum wire, however, enable commercial lamps to be made for as low as 25 watts consumption on 110-volt circuits, and abroad many 220-volt tantalum lamps are in use, two of the ordinary spiders being mounted in tandem in a single bulb. The cost of the tantalum lamp is approximately double that of the carbon lamp, but the very greatly increased efficiency makes its use desirable at all ordinary prices for current. It would in fact have come into use in enormous quantities had it not been for the subsequent production of the tungsten metallic filament lamp, which permits a still higher efficiency and is equally available on direct- and alternating-current circuits.

Shortly after the commercial appearance of the tantalum lamp experimental work on a tungsten filament was brought to a successful issue, and this metal, owing to its very refractory character, can be worked at a higher temperature than any filament yet found. Tungsten, although a comparatively rare metal, is much

more available in quantity than either osmium or tantalum. Its atomic weight is 184, its specific gravity about that of platinum, and its melting point somewhat in excess of 3000° C. Only at the highest temperatures of the electric furnace can tungsten be reduced to a state of a coherent metal. And hence most of the

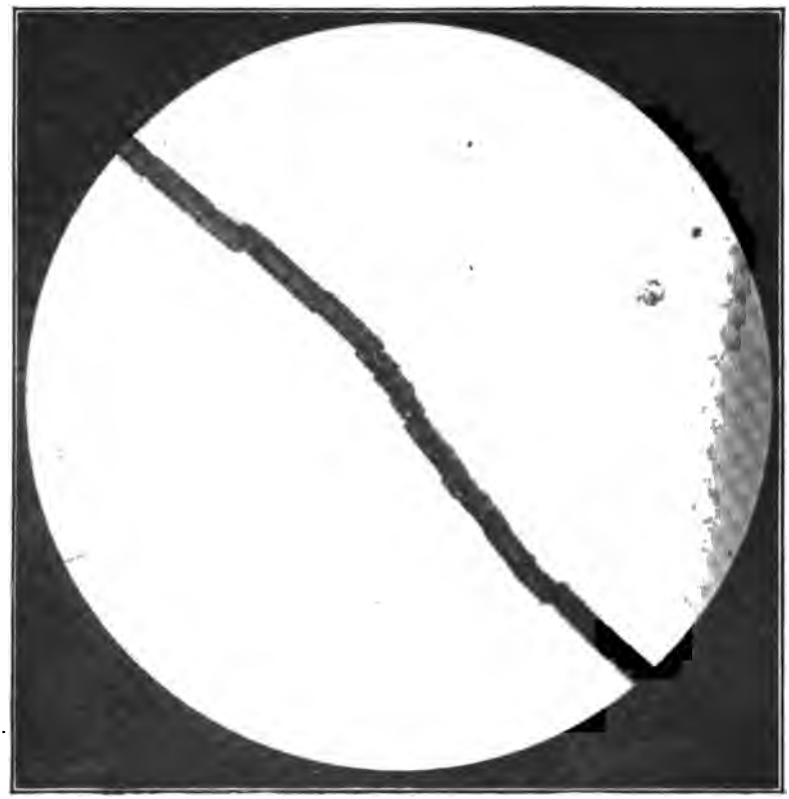


Fig. 63.

tungsten filaments have been prepared by a method analogous to that employed with the osmium filament; that is, the filament is made from a mixture or alloy of finely divided tungsten from which all other materials other than the tungsten are driven off by heat, and the filament remaining is then sintered into coherent structure by intense heat.

At least half a dozen forms of this general process have been employed, some of them involving purely mechanical mixtures like that used for the osmium filament, and others the use of compounds or amalgams reduced finally to metallic tungsten and sintered. These processes are partially kept secret and often subject to change, but they lead to the same final product, — a tungsten filament not like a drawn wire, but a sintered mass more or less dense and coherent and giving a workable although somewhat fragile filament. Owing to its enormously high melting point, the tungsten filaments can be safely worked at a temperature of something like 2300° C., at which the specific consumption is about 1.25 watts per horizontal candle power, approximately 1.5 to 1.6 watts per m. s. c. p. As in the case of other metallic filaments, the specific resistance of the metal is too low to give a conveniently short filament, so that it is necessary, as with osmium and tantalum, to use several loops in series to obtain a lamp which will burn upon the customary voltages. The ordinary 25-watt tungsten lamp of commerce usually has four such loops, carrying in all 16 to 20 inches of filament of a diameter slightly less than 0.002 of an inch. The appearance of the typical lamp is shown in Fig. 64. The filaments are usually carried as shown, on a long and rather slender spider, so that the loops are sufficiently anchored at each end. The average life of such tungsten lamps worked at an initial consumption of 1.25 watts per candle under constant pressure runs to about 1000 hours, while falling off approximately 20 per cent in candle power. Owing to the difficulties of manufacture, great uniformity is much more difficult to secure than with the carbon and tantalum filaments, and consequently a good many lamps fail by breakage after a less period of life than this; while others may run on to 2000 hours or more, leaving the average about as stated. Since tungsten, like other metals, has a positive temperature coefficient, the variation of candle power and efficiency with voltage is materially less than with carbon lamps. Fig. 65 shows for a group of 25-watt tungsten lamps the relation between watts per candle,



Fig. 64.

m. s. c. p., and voltage. The customary working temperature of a tungsten filament seems to be fairly near the limit of its economical endurance, as in the case of the working temperatures as determined by experience for other filaments, so that the increase of life with a small drop in voltage or the decrease of life with a small increase of voltage is conspicuous.

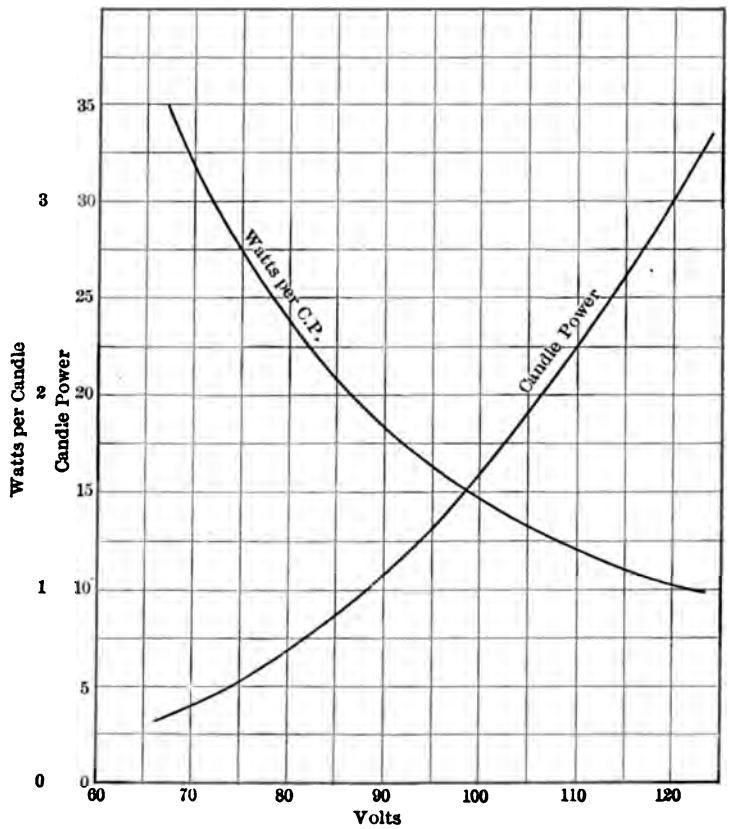


Fig. 65.

Fig. 66 shows the relation of life to voltage as determined for present commercial lamps having plain carbon, "metallized" carbon, tantalum, and tungsten filaments. It will be noted that in the case of the tungsten a drop of 2 per cent in voltage will increase the life by about 30 per cent. Tungsten lamps are regularly manufactured for the usual voltages of 110 to 120 in

sizes of 25, 40, 60, 100, 125, 150, and 250 watts; while lamps on the one hand of 15 and 20 watts, and on the other of 300, 400, and 500 watts, have been experimentally produced and are beginning to come into use. All are worked at substantially the same efficiency, save for the lamps designed, as are some of the larger sizes, for 220 to 240 volts, which are rated at about 1.4 watts per horizontal candle power. In addition, series incandescent lamps of various sizes from 40 to 250 watts for all the usual constant currents are manufactured, and these have practically driven the carbon series lamps from the field.

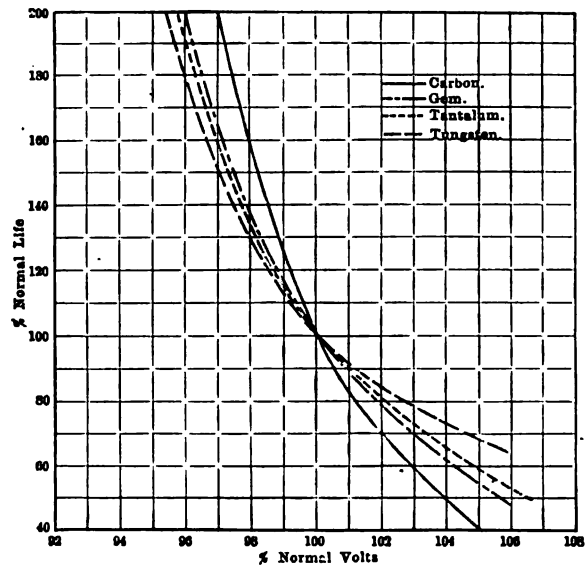


Fig. 66.

The weak point of the tungsten filament has been its fragility owing to the extreme slenderness of the filaments in the smaller lamps and the brittleness of the material. When hot the filaments are amply strong, and it is therefore desirable to turn on the lights in case the globes or shades are to be cleaned. The earlier tungsten lamps were in fact so fragile that shipment was accomplished only with great difficulty and with considerable breakage. At present the filaments, while still delicate, are much stronger than the earlier ones, and can readily be burned with

the lamp in any position, a procedure that was distinctly unwise at first.

The changes going on in the production of these tungsten lamps are so rapid that it is futile to attempt more than a cursory description of the state of the art. The lamps are now manufactured by a great number of makers both here and abroad under a wide variety of trade names, but the differences between them are mostly of a minor character. The most important recent improvement in manufacture, not yet generally introduced, is the production of a tungsten filament of drawn wire like the tantalum filament. At the extreme temperatures of the electric furnace, tungsten can be produced in true metallic state, and although brittle when cold it is moderately ductile when hot, and is drawn into wire in this state. The details of this difficult process have now been fairly well worked out, so that the drawn filaments have already come into some commercial use and show evidence of considerably greater strength and rather better life than the sintered filaments previously used. It is too early yet to speak of their exact properties. The wire drawn filaments are mounted on spiders akin to those used in the tantalum lamps.

Tungsten lamps have already gone far in driving out the carbon lamps, and prove particularly useful in the larger units, from 40 to 150 watts. The only objection to their employment is their cost and the fact that they are not yet strong enough to stand use in positions where considerable vibration is experienced. Both these difficulties are likely to be remedied to a very material extent. The present cost of tungsten lamps, being at retail from 60 cents upwards, according to size, is so considerable that breakage becomes a serious item, which is, however, more than overbalanced by the saving in current, except where current is to be had at very low rates.

Whether the tungsten lamp represents the last stage of improvement of the metallic filament remains to be seen. There is certainly no metal yet known which has a higher melting point, nor is there a reasonable expectation of finding such a metal. It is possible that the use of alloys may lead to improvement, but it is fairly certain that no alloy is likely to raise the melting point already available with tungsten, although it is highly probable that it may be possible to work out alloys of the extremely refractory metals which will improve their mechanical properties

and also raise their specific resistance, an end which is highly desirable. Many experiments have been tried and are being tried with nonmetallic filaments composed of refractory oxides and other compounds. None of these has yet reached a point where it is more than experimental, except for the Nernst lamp, about to be described, which belongs to a somewhat different class. It is worth mentioning, as a matter chiefly of theoretical interest, that practically all the modern filaments have a somewhat favorable selective radiation as compared with carbon. In other words, their radiation is more efficient than the true temperature of the filament would indicate, owing to a better distribution of energy in the spectrum.

The Nernst lamp, introduced about ten years ago, differs materially from the other incandescent lamps in that the material of the light-giving body is a nonconductor when cold and has to be operated in air rather than *in vacuo*, to the material disadvantage of its efficiency. It was, however, the first incandescent lamp of high efficiency to appear, and has found its way into considerable use both here and abroad. The basic fact taken advantage of by Dr. Nernst in the production of his lamp is that certain metallic oxides, particularly the rare earths such as are used in the Welsbach mantle, while nonconductors at ordinary temperatures, conduct fairly well when hot. This conduction is of an electrolytic nature, so that the "glowers" endure best when used on alternating current of a fairly high frequency. The fundamental principle of the Nernst lamp is the use of a glower of such material artificially heated at the start to render it a conductor and then allowed to glow under the passage of the current. Many materials are available for the glower, and its composition has been changed from time to time. In one of Nernst's original patents the composition was specified as of zirconia, erbia, and yttria. The later compositions have substituted thoria in part or wholly for the zirconia, and have also included the ceria that is found so effective in Welsbach mantles. Recent glowers are of a mixture of ceria, thoria and zirconia. Whatever the exact composition employed, the procedure in manufacture is quite similar to that used in some of the later lamp filaments, the active material being mixed with a binder, formed into slender rods, and then fired at a high temperature until nothing but the mixed oxides are left. The glower bodies themselves are one-sixty-fourth to one-thirty-second of an inch in

diameter and about one inch in effective length, the ends being tiny balls in which the leading-in wires are embedded. The glower material varies enormously in resistance with the temperature. Fig. 67 shows, from some of Nernst's own tests, the extent of this variation in specific resistance. It will be seen that at ordinary temperatures the glower is practically an insulator, while at a white heat it is a very tolerable conductor. On account of this very large negative temperature coefficient, the lamp would tend to great instability were it not for the presence of a ballast resistance in series with the glower. This ballast resistance is composed

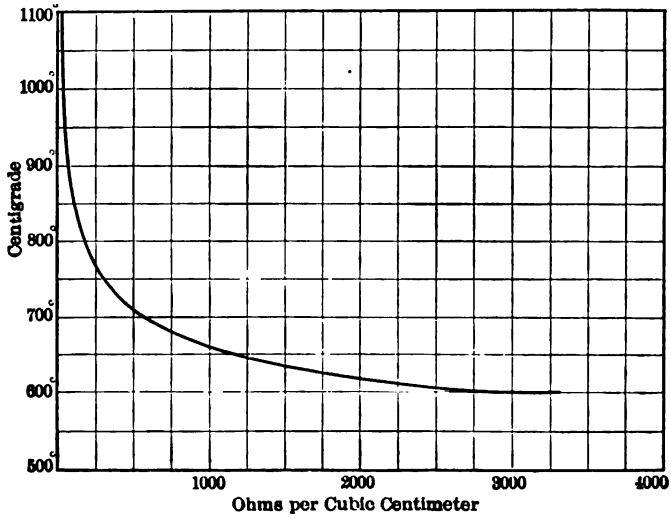


Fig. 67. — Curve of Resistance Variation.

of iron wire, which has a large positive temperature coefficient, sealed into glass tubes filled with hydrogen to prevent oxidation. For starting the lamp a heating resistance close above the glower is provided which takes all the current when the lamp is first turned on and is automatically cut out of circuit when the glower has come to its conducting temperature. Figure 68 shows the diagrammatic connections of a Nernst lamp containing three glowers. The apparatus consists of the glowers, the ballast tubes in series with them, the heater, made of wire protected by enamel, and in shunt with the glowers and ballast, and finally a cut-out magnet to remove the heater from circuit when the glowers are in action.

The larger Nernst lamps are provided with independent terminals, but the single-glower lamps screw into an ordinary lamp socket and are treated practically like any other incandescent lamp. Fig. 69 shows one of these single-glower lamps complete. It consists of a small housing attached to an ordinary lamp base, which housing contains the cut-out magnet and ballast and carries a shade supporter with a 3- or 4-inch opal ball. The burner proper, Fig. 70, carrying the glower and heater, screws into the base of the housing, making automatic connection as it goes home. The mechanical

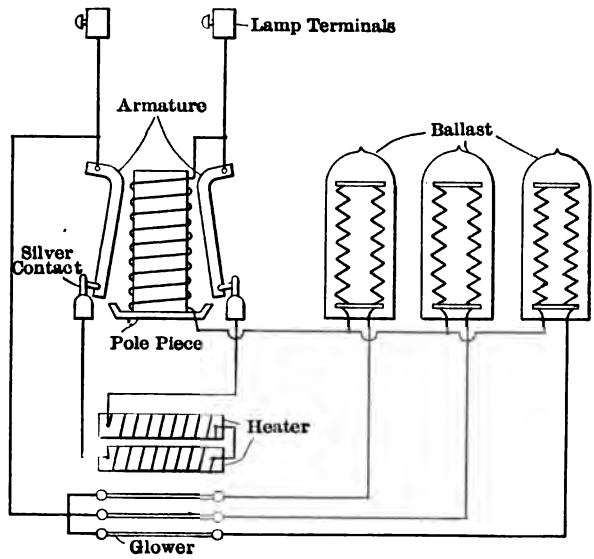


Fig. 68.

equipment is therefore reduced to the simplest possible terms, and the care required to replace a glower is no more than is demanded in screwing in an ordinary incandescent lamp. When turned on the glower comes to full incandescence in 15 to 30 seconds, and the lamp in this recent form is almost as convenient and workable as any other incandescent lamp. As now manufactured, Nernst lamps can be worked either on alternating- or direct-current circuits. The glowers for the latter are of special construction and must be burned at a definite polarity. They are readily adapted to high voltages, and all except the smallest sizes are manufactured



Fig. 69. — Single-glower Westinghouse Nernst Lamp.

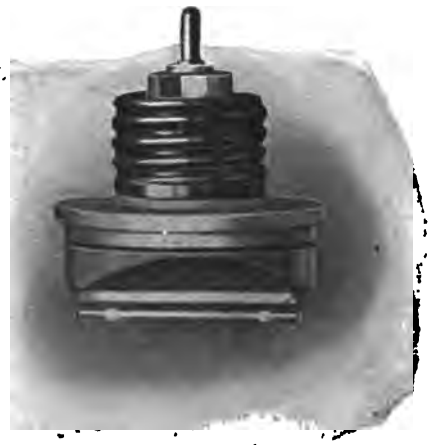


Fig. 70. — Westinghouse Nernst Screw Burner with Globe Removed.

for 220 volts. The following table gives the rating and performance of the sizes of Nernst lamp now in use from the manufacturer's data:

TABLE OF NERNST LAMP DATA.

Lamp.	Glassware (Clear).	Maximum Candle Power.	Mean Hemisphere Candle Power.	Mean Hemisphere Efficiency.	Actual Wattage under Test.
66-watt	4 inches	74	50	1.38	69 (110 v.)
88 "	4 "	105	77	1.2	92
110 "	5 "	131	96.4	1.2	115
132 "	6 "	156	114	1.2	136.8
2-glower	8 "	345	231	1.2	276
3 "	8 "	528	359	1.15	414
4 "	8 "	745	504	1.09	552

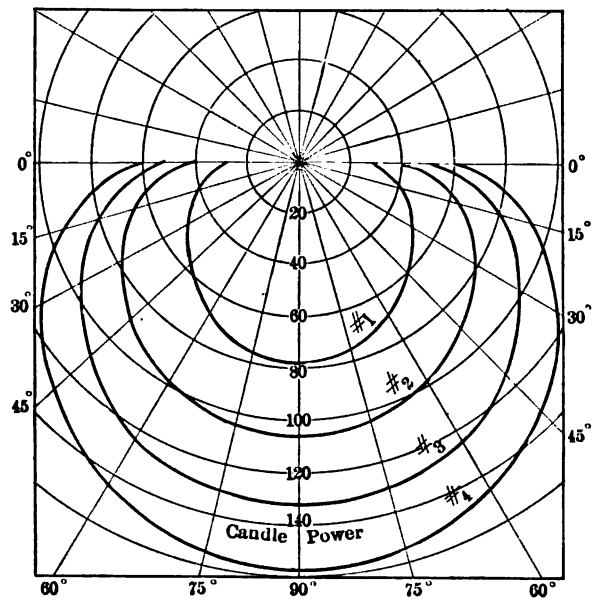


Fig. 71.

The effective life claimed for the glowers is 600 hours for the direct-current glower and 800 hours for alternating-current glowers at 60 cycles or above. At 25 cycles this life is reduced to about 400 hours. The heaters and ballast are stated to last

about 3000 and 15,000 hours respectively, and are easily replaced when necessary. Fig. 71 shows the distribution of light in the lower hemisphere of the single-glower lamps referred to in the table. The temperature reached by the Nernst glower being upwards of 2000° C., the light is of good color, about the same as that from a tungsten lamp, and the efficiency is fairly high, as will be seen from the table already given. Reckoned on the basis of mean spherical candle power, the specific consumption, including the ballast, is somewhere between 1.5 and 2 watts per candle power.

The structure of the lamp, however, requires that it should be compared with other illuminants rather on the basis of its mean lower hemispherical candle power, assuming the other lamps compared to be equipped with suitable reflectors. Aside from its convenient use as a practical illuminant, it furnishes for experimental purposes one of the most convenient of light sources, since once the lamp is in action it can be run in any position, and gives a very steady and brilliant light, the intrinsic brilliancy of the glower being about 3000 candle power per square inch. In such use the current should be held accurately uniform by means of a milli-amperemeter, and the glower must be very carefully shielded from draughts, to which it is hypersensitive.

CHAPTER VIII.

THE ELECTRIC ARC LAMP.

THE electric arc is the most intense artificial illuminant and the chief commercial source of very powerful light. A full account of it would make a treatise by itself, so that we can here treat only the phases of the subject which bear directly on its place as a practical illuminant. First observed, probably, by Volta himself, the arc was brought to general notice by Davy in 1808 in the course of his experiments with the great battery of the Royal Institution. If one slowly breaks at any point an electric circuit carrying considerable current at a fair voltage, the current does not cease flowing when the conductor becomes discontinuous, but current follows across the break, with the evolution of great heat and a vivid light. If the separation is at the terminals of two carbon rods the light is enormously brilliant, and by proper mechanism can be maintained tolerably constant. The passage of the current is accompanied by the production of immense heat, and the tips of the carbon rods grow white hot, and serve as the source of light. In an ordinary arc lamp the upper carbon is the positive pole of the circuit, and is fed slowly downward, so as to keep the arc uniform as the carbon is consumed. The main consumption of energy appears to be at the tip of this positive carbon, which is by far the most brilliant part of the arc, and at which the carbon fairly boils away into vapor, producing a slight hollow in the center of the upper carbon, known as the "crater."

The carbon outside the crater takes the shape of a blunt point, while the lower carbon is rather evenly and more sharply pointed, and tends, if the arc is short, to build up accretions of carbon into somewhat of a mushroom shape. Fig. 72 shows the shape of these tips much enlarged, as they would appear in looking at the arc through a very dark glass. Under such circumstances the light from the arc between the carbon points seems quite insignificant, and it is readily seen that the crater is by far the hottest and most brilliant region. In point of fact the crater may reach a temper-

ature of probably 3500° to 4000° C., and gives about 50,000 candle power per square inch of surface — sometimes much more.

It is obvious that the more energy spent in this crater the more heat and light will be evolved, and that the concentration of much energy in a small crater ought to produce a tremendously powerful

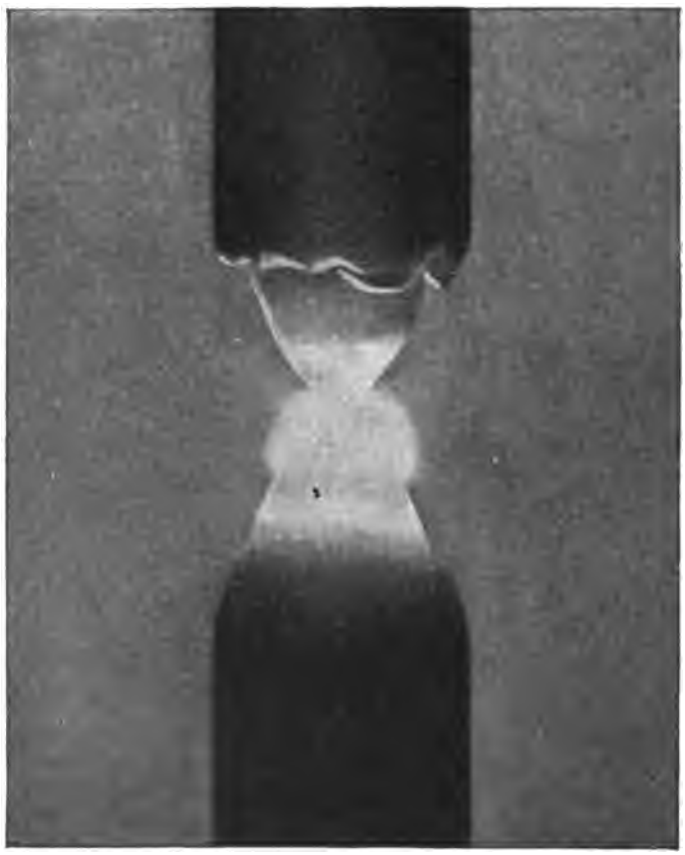


Fig. 72. — The Electric Arc.

arc. It is not surprising, therefore, to find that the larger the current crowded through a small carbon tip, — in other words, the higher the current density of the arc, — the more intense the luminous effects and the more efficient the arc. Fig. 73 shows this fact graphically, giving the relation between current density and light in an open arc maintained at uniform current and voltage.

The change in density of current was obtained by varying the diameter of the carbons employed, the smallest being about five-sixteenths inch in diameter, the largest three-fourths inch. The current was 6.29 amperes, and the voltage about 43.5. The efficiency of the arc appears from these experiments to be almost directly proportional to the current density. But if the carbon is too small it wastes away with inconvenient rapidity, while if it be too large the arc does not hold its place steadily and the carbon gets in the way of the light.

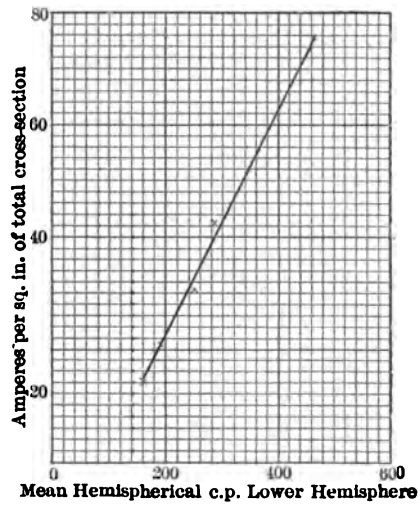


Fig. 73. — Relation between Current Density and Intensity.

The higher the voltage the longer arc can be successfully worked, but here again there are serious limitations. With too short an arc the carbons are in the way of the light, and the lower carbon tends to build up mushroom growths, which interfere with the formation of a proper arc. In arcs worked in the open air the arc is ordinarily about an eighth of an inch long. If the voltage is raised above the 40 to 45 volts at the arc commonly employed for open arcs, the crater temperature seems to fall off and the arc gets bluish as it lengthens from the larger proportion of light radiated by the glowing vapor between the carbon poles.

So it comes about that commercial arcs worked in the open air generally run at from 45 to 50 volts, and from 6 to 10 amperes.

The softer and finer the carbons the lower the voltage required to maintain an arc of good efficiency and proper length, so that arcs can be worked successfully at 25 to 35 volts with proper carbons, and with very high efficiency, but at the cost of burning up the carbons rather too rapidly. Abroad, where both high-grade carbons and labor are cheaper than in this country, such low-voltage arcs are freely used with excellent results, and give a greatly increased efficiency. Sometimes three are burned in series across 110-volt mains, where in American practice one, or at most two, arc lamps would be used, in series with a resistance coil, the same amount of energy being used in each case. With proper carbons too, a steady and efficient arc can be produced taking only 3 or 4 amperes, and admirable little arc lamps of such kind are in use on the Continent. The carbons are barely as large as a lead pencil and the whole lamp is proportionately small, but the light is brilliant and uniform.

The upper carbon burns away about twice as fast as the lower, and the rate of consumption is ordinarily from 1 to 2 inches per hour, in commercial open arc lamps.

The carbons themselves are generally about one-half inch in diameter, and one or both are often cored, i.e., provided with a central core, perhaps one-sixteenth inch in diameter, of carbon considerably softer than the rest. This tends to hold the arc centrally between the carbons and also steadies it by the greater mass of carbon vapor provided by the softer portion. Generally it is found sufficient to use one cored and one solid carbon in each arc, although in this country arcs burning in the open air usually are provided with solid carbons only.

In American practice such open arcs have almost passed out of use, being replaced by the so-called inclosed arcs and by the still more recent luminous and flaming arcs. During the past ten years all these have gone into use in immense numbers, until at the present time the open arc is very rarely installed, and illuminating companies are discarding them as rapidly as they find it convenient to purchase improved equipment.

The principle of the inclosed arc is very simple. It merely consists in fitting around the lower carbon a thin, elongated vessel of refractory glass with a snugly fitting metallic cap through which the upper carbon is fed, the fit being as close as permits of proper feeding. The result is that the oxygen is quickly burned out of the

globe, and the rapid oxidation of the carbon ceases, the heated gas within checking all access of fresh air save for the small amount that works in by diffusion through the crevices.

The carbon wastes away at the rate of only something like one-eighth inch per hour under favorable circumstances, and the lamp only requires trimming once in six or eight full nights of burning, instead of each night. For all-night lighting it used to be necessary to employ a double-carbon lamp, in which were placed two pairs of carbons, so that when the first pair was consumed the second pair would automatically go into action and finish out the night. The inclosed lamp burns 100 hours or more with a single trimming. Even much longer burning than this has been obtained from a 12-inch carbon, such as is customarily used, but one cannot safely reckon on a better performance without very unusual care.

Fig. 74 shows a typical inclosed arc lamp, of the description often used on 110-volt circuits, both with and without its outer globe and case. The nature of the inner globe is at once apparent, but it should also be noted that the clutch by which the carbon is fed acts, as in many recent lamps, directly upon the carbon itself, thereby saving the extra length of lamp required by the use of a feeding rod attached to the carbon. Finally, at the top of the lamp is seen a coil of spirally wound resistance wire. The purpose of this is to take up the difference between 110 volts, which is the pressure at the mains, and that voltage which it is desired to use at the arc and in the lamp mechanism.

Such a resistance evidently involves a considerable waste of energy, but in the inclosed arc the voltage at the arc itself is, of necessity, rather high, 70 to 75 volts, so that the waste is less than it would otherwise be.

It has been found that when burning in an inner globe without access of air, the lower or negative carbon begins to act badly, and to build up a mushroom tip, when the voltage falls below about 65 volts. Hence it is necessary to the successful working of the scheme that the arc should be nearly twice as long as when the carbons are burning in open air. This has a double effect, in part beneficial, in part harmful. With the increased length the crater practically disappears, and the light is radiated very freely without being blocked by the carbons. Hence the distribution of light from the inclosed arc is better than from an open arc.

On the other hand, there is no point of the carbon at anything like the temperature of the typical open-arc "crater," and the intrinsic efficiency is thereby greatly lowered. Also, if the inclosed arc is to take the same energy as a given open arc, the current in the former must be reduced in proportion to the increased voltage, hence, other things being equal, the current density is lowered, which also lowers the efficiency.



Fig. 74. — Typical Inclosed Arc Lamp.

The compensation is found in the lessened care and the lessened annual cost for carbons. The carbons themselves have to be of a special grade, and are about two and a half times as expensive as plain solid carbons, but the number used is so small that the total cost is low. There is some extra expense on account of breakage of the inner globes, but the saving in labor and carbons far outweighs this. Moreover, the light, while decidedly bluish white, is much steadier than that of the ordinary open arc, and the inner globe has material value in diffusing the light, being very

often of opal glass, so that the general effect is much less dazzling than that of an open arc, and the light is better distributed.

In outdoor lighting the greater proportion of nearly horizontal rays from the inclosed arc is of considerable benefit, while in buildings the same property increases the useful diffusion of light, as will be presently shown. Of course, when inclosed arcs are operated in series, as in street lighting, the resistance of Fig. 74 is reduced to a trivial amount, or abolished, so that the extra voltage required with the inclosed arc is the only thing to be considered. The inclosed arc used in this way is very materially steadier as an illuminant than an open arc taking the same current, and experience shows that it may be substituted for an open arc, taking about the same energy, with general improvement to the illumination.

The weak point of the open arc is its bad distribution of light, which hinders its proper utilization. The fact that most of the light is delivered from the crater in the upper carbon tends to throw the light downward rather than outward, and much of it is intercepted by the lower carbon. Fig. 75 gives from Wybauw's experiments the average distribution of light from 26 different arc lamps, representing the principal American and European manufacturers. The radii of the curve give the intensities of the light in various angles in a vertical plane. The distribution of light in space would be nearly represented by revolving this curve about a vertical axis passing through its origin, although at any particular moment the distribution of light from an arc may be far from equal on the two sides.

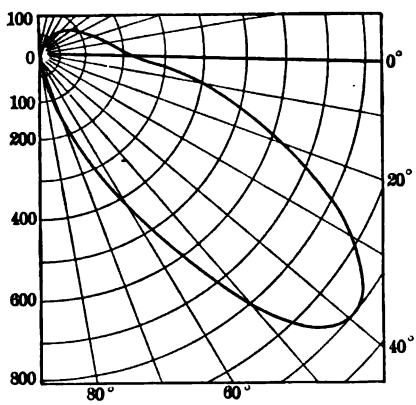


Fig. 75. — Distribution of Light from an Open Arc.

The shape of the curve is approximately a long ellipse with its major axis inclined 40 degrees below the horizontal. The presence of globes on the lamps may modify this curve somewhat, but in ordinary open arcs it always preserves the general form shown. The small portion of the curve above the horizontal plane shows the light derived from the lower carbon and the arc itself, while

the major axis of the curve measures the light derived from the crater. The tendency, then, of the open arc is to throw a ring of brilliant light downward at an angle of 40 degrees below the horizontal, so that within that ring the light is comparatively weak, and without it there is also considerable deficiency. Hence the open arc, if used out of doors, fails to throw a strong light out along the street, while the illumination is strong in a zone near the lamp.

For the same reason the open arc is at a disadvantage in interior lighting, for the reason that most of the light, being thrown downward, falls upon things and surfaces far less effective for diffusion than the ordinary walls and ceiling. Hence one of the very best ways of using arcs for interior lighting is to make the lower carbon positive instead of the upper, and to cut off all the downward light by a reflector placed under the lamp. Then practically all the light is sent upward and outward to be diffused by the walls and ceiling.

The inclosed arc, on the other hand, gives a much rounder, fuller curve of distribution, the light being thrown well out toward the horizontal, and there is also a pretty strong illumination above the horizontal.

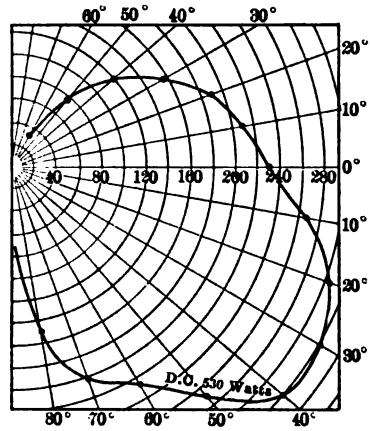


Fig. 76. — Distribution of Light from Inclosed Arc.

Fig. 76 shows a composite distribution curve from ten or a dozen inclosed arc lamps, such as are used on constant-potential circuits, including various makes. Most of them were lamps taking about 5 amperes, and therefore using nearly 400 watts at the arc, besides the energy taken up in the resistance and the mechanism. These figures include the inner globe, of course, generally of opal glass, which is of some benefit in correcting the strong bluish tinge which is produced by the long arc. After a few hours' burning a slight film collects on the inner globe, which tends to the same result.

As ordinarily employed, inclosed arc lamps take from 5 to 7 amperes, although now and then 3- or 4-ampere lamps are used. These smaller sizes are very unsatisfactory in the matter of color of the light, and are not widely used.

Outside of America the inclosed arc is little used, for abroad labor is much cheaper than here, and carbons of a grade costly or quite unattainable here are there reasonably cheap, so that the considerably higher efficiency of the open arc compensates for the extra labor and carbons. Aside from this, the bluish tinge of the light from inclosed arcs of small amperage is considered objectionable, and the gain in steadiness so conspicuous in American practice almost or quite disappears when the comparison is made with open arcs taking the carbons available abroad.

At its best the carbon electric arc has fully three times the efficiency of a first-class carbon incandescent lamp, but this advantage is somewhat reduced by the need of diffusing globes to keep down the dazzling effect of the arc and to correct the distribution of the light. Taking these into account, and also reckoning the energy wasted in the resistances in case of arc lamps worked from constant-potential circuits, the gain in efficiency is considerably reduced, and if one also figures the better illumination obtained by using distributed lights in incandescent lighting, the arc lamp has a smaller advantage than is generally supposed. Many experiments bearing on this matter have been made, and a study of the results is highly instructive.

By far the most complete investigation of the properties of the inclosed type of arc lamps is that made by a committee of the National Electric Light Association a few years ago. The investigation was upon the arc lamps both for direct and alternating currents, as customarily used on constant-potential circuits. The results, however, are not materially different, so far as distribution of light goes, from those that belong to similar lamps for series circuits. Fig. 76 is the composite curve of distribution obtained by this committee in the tests of direct-current lamps.

The weak point of such lamps as efficient illuminants lies in the large amount of energy wasted in the lamp mechanism, including the resistance for reducing the voltage of the mains to that desirable for the inclosed arc. This loss amounts ordinarily to nearly 30 per cent of the total energy supplied, so that while the arc itself is highly efficient the lamps as used are wasteful. No one but an American would think of working a 75-volt arc off a 120-volt circuit and absorbing the difference in an energy-wasting resistance, but the advantages of the inclosed arc are so great in point

of steadiness and moderate cost of labor that the bad practice has been considered commercially advantageous.

At present alternating-current arc lights are being rather widely used, both on constant-potential and on constant-current circuits, and such arcs present some very interesting characteristics. Evidently when an arc is formed with an alternating current there is no "positive" and no "negative" carbon, each carbon being positive and negative alternately, and changing from one to the other about 7200 times per minute — 120 times per second.

Under these circumstances no marked crater is formed on either carbon, and the two carbons are consumed at about an equal rate. As a natural result of the intermittent supply of energy and the lack of a localized crater, the average carbon temperature is considerably lower than in case of the direct-current arc, and the real efficiency of the arc as an illuminant is also much lowered. Tests made to determine this difference of efficiency have given somewhat varied results, but it seems probable that for unit energy actually applied to the arc itself the direct-current arc will give somewhere about 25 per cent more light than the alternating-current arc. But since when working the latter on a constant-potential circuit the surplus voltage can be taken up in a reactive coil, which wastes very little energy, instead of by a dead resistance, which wastes much, the two classes of arcs then stand upon a more even footing than these figures indicate. This comparison assumes inclosed arcs in each case.

The chief objection to the alternating-current arc has been the singing noise produced by it. This is partly due to the vibration produced in the lamp mechanism and partly to the pulsations impressed directly on the air by the oscillatory action in the arc itself. The former can be in great measure checked by proper design and manufacture, but the noise due directly to the arc is much more difficult to suppress.

Abroad, where, for the reason already adduced, open arcs are commonly used, a specially fine, soft carbon is used for the alternating arcs, and the noise is hardly perceptible. These soft, volatile carbons, particularly when used at a considerable current density, give such a mass of vapor in the arc as to endow it with added stability and to muffle the vibration to a very marked degree. The result is a quiet, steady, brilliant arc of most excellent illuminating power. But in this country such carbons are with

difficulty obtainable, and, even if they were to be had at a reasonable price, could not be used in inclosed-arc lamps on account of rapid smutting of the inner globe.

In selecting alternating-current lamps for indoor work, great care should be exercised to get a quiet lamp. Some of the American lamps when fitted with tight outer globes and worked with a rather large current are entirely unobjectionable, but in many

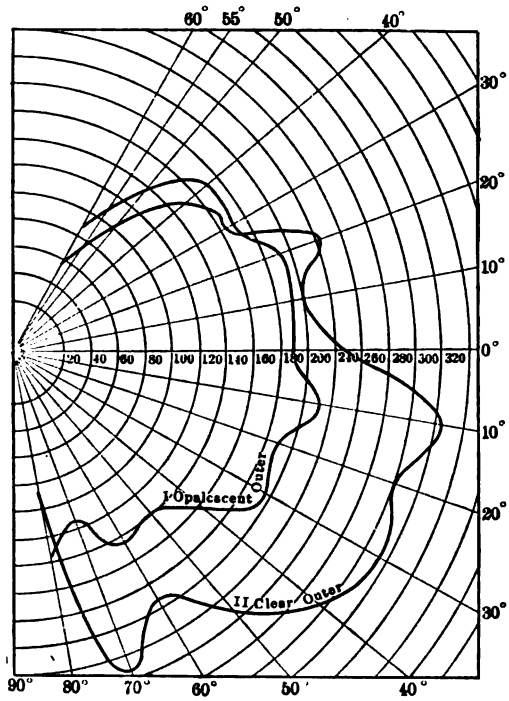


Fig. 77. — Distribution from Alternating Inclosed Arc.

cases there is noise in the mechanism, or the globe serves as a resonator. With a current of 7 to 7.5 amperes, and a well-fitted and nonresonant globe, little trouble is likely to be experienced. Out of doors, of course, a little noise does not matter.

The chief characteristic of the alternating arc, as regards distribution of light, is its tendency to throw its light outward rather than downward like the direct-current arc; in fact, considerable light is thrown above the horizontal, which materially aids diffusion.

For this reason it is often advantageous to use reflecting shades for such lamps, so as to throw the light out nearly horizontally when exterior lighting is being done. Indoors, diffusion answers the same purpose, unless powerful downward light is needed, when the reflector is of service.

Fig. 77, from the committee report already mentioned, shows the distribution of light from an alternating-current lamp fitted with a porcelain reflecting shade, with an opalescent outer globe, and with a clear outer globe. The abolition of the outer globe and the use of the reflector produce a prodigious effect in strengthening the illumination in the lower hemisphere, and this hemispherical illumination is for some purposes a convenient way of reckoning the illumination of the lamp. But a truer test is the spherical candle power, since that takes account of all the light delivered by the lamp. Alternating arc lamps seem to work best at a frequency of 50 to 60 cycles per second. Above 60 cycles they are apt to become noisy, and below about 40 cycles the light flickers to a troublesome extent. The light of the alternating arc is really of a pulsatory character, owing to the alternations. A pencil rapidly moved to and fro in the light of such an arc shows a number of images—one for each pulsation; and this effect would be very distressing if one had to view moving objects, like quick running machinery, by such light. A harrowing tale is told of a certain theater in which alternating arcs were installed for some gorgeous spectacular effects, and of the extraordinary centipedal results when the ballet came on.

This pulsation is somewhat masked when the inclosed arc is used, even with a clear outer globe, and is generally rather inconspicuous when an opal outer globe is used. It is also reduced when a fairly heavy current (7 to 8 amperes) is used, and when very soft carbons are employed, as they can be in open arcs.

An interesting comparison of direct-current and alternating-current inclosed arcs, as used on constant-potential circuits, is found in the following table, from the report already quoted.

It must be remembered that the results are in Hefner units. This unit is exactly 0.9 candle power, so that the mean results, reduced to a candle-power basis, are, for efficiency when using clear outer globes, as follows:

Direct-current arc.....	2.89 watts per candle power.
Alternating arc.....	2.96 watts per candle power.

D. C. Lamp.	Current.	Watts Consumed.			Mean Intensity in Heat Units.			Mean Watts.		
					Spherical.		Lower Hemispherical.	Spherical Heat Units.		Lower Hemispherical.
		In Lamp.	In Arc.	Mechanism.	Op. Outer.	Clear Outer.	Clear Outer.	Op. Outer.	Clear Outer.	Clear Outer.
.....	.....	.....	.....	.....	.....	235	332	.....	2.37	1.66
1	5.01	551	401	150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559	406	252	195	216	282	2.85	2.60	1.99
4	4.76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.16†	458	333	125	154	174	221	2.96	2.63	2.07
7	4.76	524	381	143	203	333	317	2.63	2.20	1.65
9	4.84	532	387	145	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.74	2.24	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98

A. C. Lamp.	Current.	In Lamp.	Power Factor Lamp.	In Arc.	Power Factor Arc.	Mechanism.						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
.....	.....	.....	.....	.....	.....	.....	.....	203	236	.....	2.26	1.94
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
.....	.....	.....	.....	.....	.....	.....	.....	153	169	.....	2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.30	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

* Condition of no outer globe. † Condition with shade on lamp.
NOTE. — All marked values not included in the mean.

These efficiencies are on their face but little better than those obtained from incandescent lamps. There is little doubt that as a matter of fact a given amount of energy applied even to 3-watt incandescent lamps will give more useful illumination than if used in arcs of the types here shown. The incandescents lose somewhat in efficiency, but gain by the fact of their distribution in smaller units. In comparison with tungsten lamps these arcs are hopelessly outclassed and are now obsolescent.

But for some purposes the arcs are even now preferable on account of their whiter light and the very brilliant illumination that is obtainable near them.

Both direct- and alternating-current inclosed arcs gain, by the use of rather large currents, both in steadiness and in efficiency, and moreover give a whiter light. The same is true, for that matter, of open arcs, in which the larger the current the higher

the efficiency. Very many experiments on the efficiency of open arcs have been made, with moderately concordant results. Their efficiency ranges in direct-current arcs from about 1.25 watts per candle in the smallest to about 0.6 or a little less in the most powerful. Fig. 78 shows considerable number of results by different experimenters consolidated into a curve giving the relation between current and efficiency, as based on mean spherical candle power.

There is generally accounted to be about 25 per cent difference in absolute efficiency in favor of the continuous-current arc.

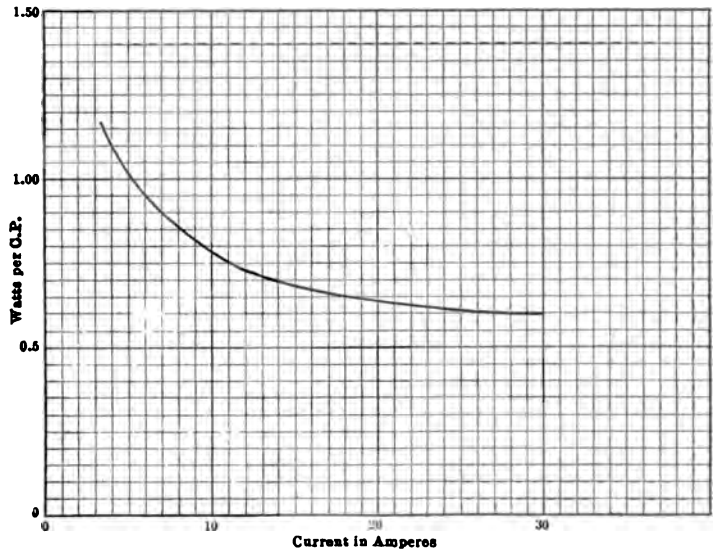


Fig. 78. — Relation between Current and Efficiency.

Within the past three or four years a good many so-called intensive arcs have come into use, at first abroad and later in this country. These are practically inclosed arcs worked at very high current density. They are usually small lamps for indoor use taking from four to five amperes and having electrodes one-fifth to one-fourth of an inch in diameter instead of the usual one-half inch or thereabouts.

The result is, as would be anticipated from Fig. 78, a very great increase in efficiency, since the current density is about four or five times greater than usual in the earlier arc lamps. There is

an additional advantage gained from the small carbons in that the crater is less marked and less sheltered, almost the entire end of the carbon being raised to a very vivid incandescence. These arcs are usually fitted with a single small opal globe, although sometimes a clear inner globe and an exterior opal globe are employed.

The specific consumption of such arcs commonly runs from 1 to 1.5 watts per mean lower hemispherical candle power, which places them in the same class with regard to efficiency as the recent metallic filament incandescent lamps. The intensive arc, however, has an enormous advantage in the matter of color. Even the most efficient of the metallic filament incandescents are still considerably off white, while the intensive arc is a sufficiently close approximation to sunlight for almost any practical purpose, and is by far whiter than any other illuminant suitable for general commercial purposes. For use in shops where color matching has to be done, the intensive arc is the only efficient illuminant as yet available which gives approximately sunlight values to the colors, and by reason of this advantage it has come into extended use and is rapidly driving out the older illuminants in cases where critical color matching is important. The intensive arcs require a little more care than their predecessors, inasmuch as the mechanism is somewhat more delicate, and the life of the carbons is from 20 to 50 or 60 hours instead of at least double this period as in the ordinary inclosed arcs. The difference in steadiness, color, and efficiency, however, is so great as to leave no comparison between the two for practical indoor illumination.

With the exception of the intensive arc just mentioned, all forms of carbon arc are rapidly becoming obsolescent in this country. They have indeed little excuse for existence from the standpoint of efficiency since the introduction of arcs of the so-called luminous and flaming types. These are widely separated from previous arcs in that their light is due, not mainly to the high incandescence of the electrodes, but to the incandescent vapors of the arc stream itself.

The flaming arcs employ electrodes charged with easily vaporizable metallic salts which give intense light from the vapor streaming between the poles. This light, like other light from incandescent vapors, shows a discontinuous spectrum. The efficiency of the light emitted, therefore, does not depend, as in the case of incandes-

cent solids, upon the absolute temperature, but rather upon the special character of the vapor; and as a result it is thus feasible to obtain luminous efficiencies very much higher than could practically be reached by any incandescent solid. The substances used for mineralizing the electrodes are very various. The chief one is calcium fluoride, which possesses the somewhat unusual property of giving a discontinuous spectrum as a compound. It is sometimes mixed with the analogous strontium and barium fluorides, in order to modify the color, strontium giving a ruddy tinge and the addition of barium making the light somewhat whiter. The calcium fluoride by itself gives a brilliant golden-yellow light of very high value in luminosity, but yet of too strong hue to be altogether pleasing, so that the lamp using such electrodes is better suited for outdoor work than for interior work.

In fact, all the flaming and luminous arcs give off a considerable amount of solid fumes composed of oxides of the metals concerned, which are somewhat objectionable in interior lighting. Carbon possesses for such work the unique advantage of producing an oxide that is gaseous, colorless, and odorless.

Some electrodes for flaming arcs are also charged with a certain quantity of rare earths, by-products of Welsbach mantle manufacture, which give a nearly white flame. All the substances here mentioned have white or yellowish-white oxides, a point of some practical importance with respect to the results of the fumes produced.

Still another group of flaming arcs, usually known in this country as luminous arcs, are charged with compounds of iron, titanium, and chromium in various proportions, some minor constituents being occasionally added to these. These arcs, the spectra of the metals being enormously rich in widely distributed lines, give a much whiter light than the arcs charged with the calcium group of metals, and the electrodes are consumed much less rapidly, an advantage which is punished by a somewhat lower efficiency. They also give off a smudge of dark-colored oxides difficult to take care of in the lamp, and require very active ventilation to keep the globes clear. The two groups of arcs just mentioned are of quite different character in some important respects and perform very differently in practice, though both are widely and successfully used.

Taking up first the flame lamps proper, in which the electrodes are carbon sticks, one or both of them "mineralized" usually with

calcium fluoride, the early types of these lamps were commonly arranged for the use of inclined electrodes forming an acute angle with each other and fed down through the lamp casing into a globe at the extreme bottom of the lamp. Fig. 79 gives the appearance of a typical lamp of this kind and Fig. 80 shows the arrangement

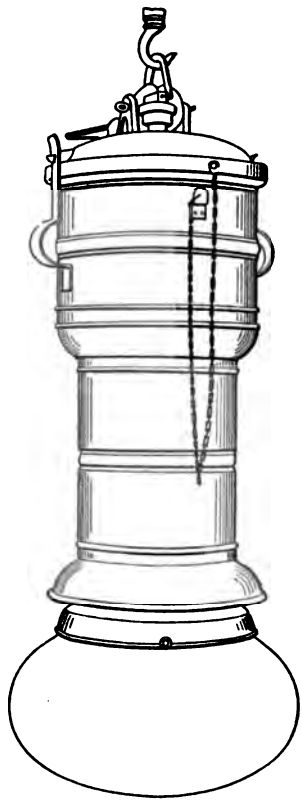


Fig. 79.

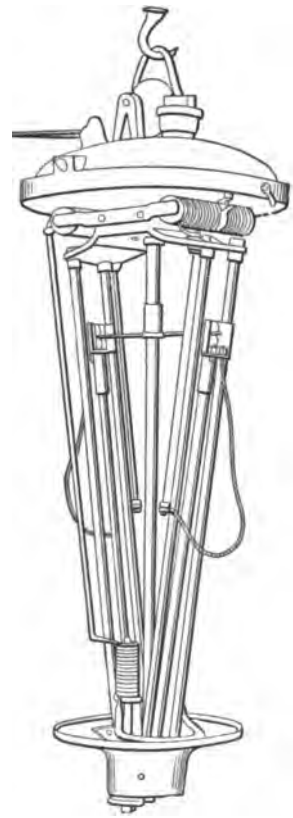


Fig. 80.

of the electrodes and mechanism. The two carbons, converging, meet in a cup-shaped hollow at the extreme bottom of the lamp casing lined with refractory material. The arc is struck by swinging one of the carbons slightly and is kept in place within the cup and prevented from running up on the carbons by the repulsion of a slight magnetic field established by a magnet near the bottom

of the casing. This is the same principle employed in the old Jamin candle in use more than thirty years ago.

Such flame arcs are made both for direct and alternating current. In the former case sometimes only one carbon, the positive one, is mineralized, the negative electrode being a plain carbon stick of somewhat smaller diameter, so that the electrodes will burn away uniformly. Sometimes the mineralized carbon is furnished with a slender wire as a core to increase the conductivity. In some cases both electrodes have been mineralized, the amount and distribution of the mineral material having varied greatly in different lamps. The electrodes are long, commonly from 18 to 24 inches, and burn at the rate of 1 to 1¼ inch per hour, so that the burning life is commonly from 14 to 18 hours. The voltage at the arc is 40 to 45, and the current is usually 10 to 12 amperes.

Such lamps are adapted to run two in series on ordinary multiple circuits. Each lamp gives an output of approximately 1200 to 1400 mean spherical candle power at a specific consumption of 0.4 to 0.5 watt per mean spherical candle power, reckoning the energy at the lamp terminals so to include the small steadying resistance which is needful in case of multiple lamps worked in this way. These figures are true only for the lamp charged with calcium fluoride, those modified to give a ruddy or whiter light having materially less efficiency. The alternating-current lamps of similar type operate at a specific consumption of between 0.6 and 0.7 watt per mean spherical candle power. All these figures apply to the lamp, as usually equipped, with an opal globe.

These inclined carbon flame arcs have come into very wide use in this country mainly for display lighting and the illumination of very large interiors; abroad, for both commercial and street lighting. Fig. 81 shows a typical distribution curve from a direct-current lamp of this class.

More recently another type of flame arc, primarily due to Professor Blondel, has been very successfully introduced. In this the carbons are vertical, as in an ordinary arc lamp, the heavily mineralized positive carbon being below, while usually a plain carbon is employed above. The positive carbon in this, as in the previous lamps, is the larger in diameter, and the lamp is furnished with a focusing feed, so that the arc is maintained in one position just below a little cup of refractory material through which the upper carbon passes. Lamps of this class have shown most extraor-

dinary results in efficiency, and the vertical carbons give a better curve of distribution for outside work than do the converging carbons. The voltage at the arc is ordinarily a scant 40 volts, and

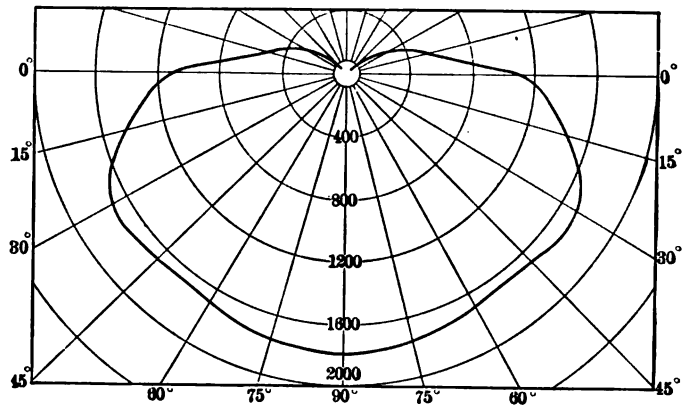


Fig. 81.

the lamps are burned two in series on multiple circuit. They can also, like other flame lamps, be conveniently adapted for use on series circuits if desirable. They work well on a somewhat smaller current than is usual with the inclined carbon lamps. Fig. 82 shows the Blondel lamp as manufactured by Crompton & Co. This is made both with single carbons and with double carbons for longer burning, following the practice of the earlier open arcs. The consumption of the electrodes is less rapid than in the usual electrodes for inclined lamps, amounting to 0.8 inch per hour or less according to current. One pair of 15-inch carbons lasts about 17 hours at 10 amperes and about 22 at 7 amperes. The electrodes generally used give the same yellowish light as other ordinary flame-arc electrodes. Fig. 83 shows the actual results of tests of a lamp of this type arranged for series burning at a current of 6.6 amperes. The watts per mean spherical candle power were 0.46, while the watts per mean lower hemi-



Fig. 82.

spherical candle power dropped to 0.326, a very extraordinary performance for an arc taking only about 260 watts at the terminals and equipped with an opal globe. Similar arcs at 8 to 10 amperes give an efficiency materially higher even than this.

The chief practical trouble with the flame arc being the necessity of frequent trimming, the attention of inventors has been lately drawn toward the production of long-burning electrodes, either by increasing the length or cross section or slightly modifying the

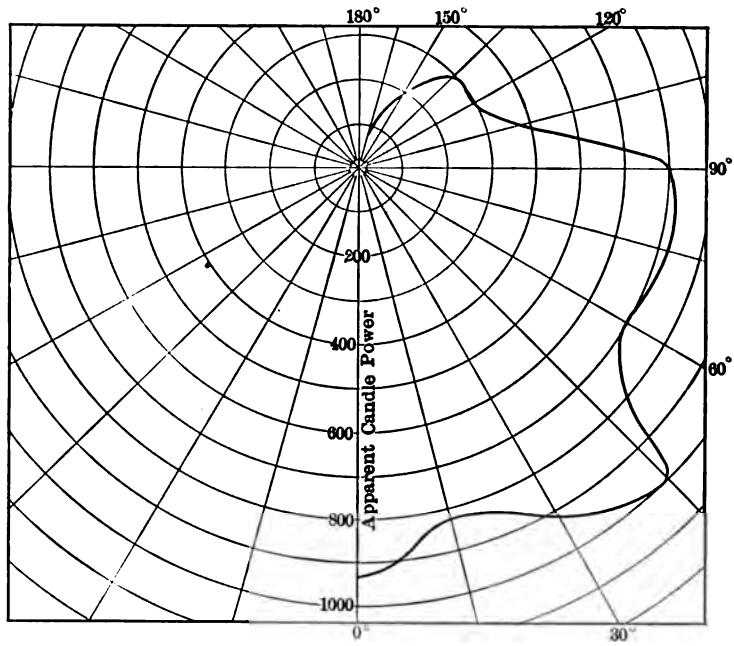


Fig. 83.

composition. The first and perhaps best known of the long-burning lamps is the Jandus regenerative flame lamp of which the general appearance is shown in Fig. 84 and the cross section in Fig. 85. The peculiarity of the lamp is the provision of two cooling chambers, of cast iron enameled white, which pass outside the globe and connect with the lamp casing above and below. The arc itself burns in an inner clear-glass flue surrounded by the ordinary opal globe. Air is admitted from the bottom and the fumes from the lamp pass upward and outward into the cooling flues, where they

are deposited, so that the chimney and globe are kept reasonably free from them, and consequently the arc can burn for a much longer period without producing an opaque coating.



Fig. 84.

The lower, heavily mineralized, electrode is a carbon stick of stellate cross section. The active material is packed into the eight channels between the eight arms of the star, the electrode being about one inch in diameter. The upper negative electrode is a cored carbon stick. These lamps are adapted for currents of 5 to 7 amperes, and, owing to the comparatively complete inclosure of the arc, the arc voltage runs high, — 70 to 90 volts, — so that the lamp with a small steadying resistance can be burned singly on constant-potential circuits if it is desirable. It also lends itself readily to use on series circuits. Fig. 86 shows the distribution curve of such a lamp worked on a series circuit of 6.7 amperes. It will be seen that the distribution is a favorable one for outside lighting, and the efficiency is high, the specific consumption reckoned at the terminals of the lamp being 0.58 watt per mean spherical candle power and 0.36 watt per mean lower hemispherical candle power. The life of the electrodes is approximately 75 hours at this current, and it should be noted that the condensing chambers, owing to the intensity of the surface radiation from the opal globe, do not cast a noticeable shadow.

An interesting type of flame-arc lamp for series circuits has recently been introduced by the General Electric Company in this country and is employed to some extent in street illumination, particularly in the case of open squares. This is a vertical carbon lamp with electrodes of a slightly different composition from those heretofore mentioned, and especially adapted to work on moderate currents. Fig. 87 shows the distribution curve of this light as used in street lighting practice in Boston, Mass., equipped with a fairly dense Alba globe and enameled reflector. It is inter-

esting, from the exceptionally good distribution, for lighting large areas. The specific consumption with this particular globe is 0.35 watt per mean lower hemispherical power. This represents the ordinary burning condition of the lamp, no pains being taken to keep the globe free from the deposit. With a clear or very light opal globe kept rigorously clean during a test the efficiency figures would run somewhat higher. The life of the electrodes is about 20 hours.

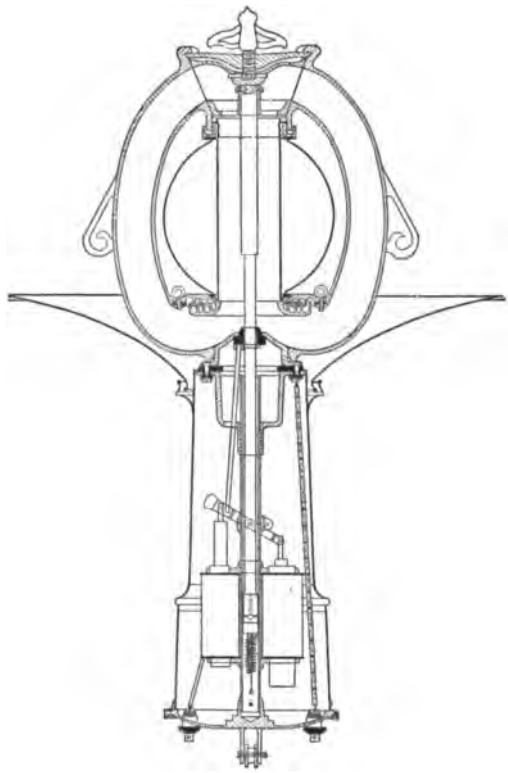


Fig. 85.

Within the past two or three years some remarkable white-flame electrodes, under the name of Alba, or T. B., have been produced by Siemens and Halske, to which reference has already been made. These have very nearly as high an efficiency as the best of the yellow-flame electrodes, and are adapted for burning in various forms of flame arcs. They are widely employed abroad for street

lighting in the Siemens and Halske vertical carbon lamps, and give at very high efficiency a light that in color is quite indistinguishable from that of a first-class carbon arc. All the flame lamps suffer in this country from a strong prejudice against frequent trimming and from the high cost of the electrodes, which are not yet produced in large amounts here and are heavily punished by the customs duties.

To meet American requirements, a radically different type of arc, commonly known as the luminous arc, has come into very extensive use. This is essentially a flame arc, but the active

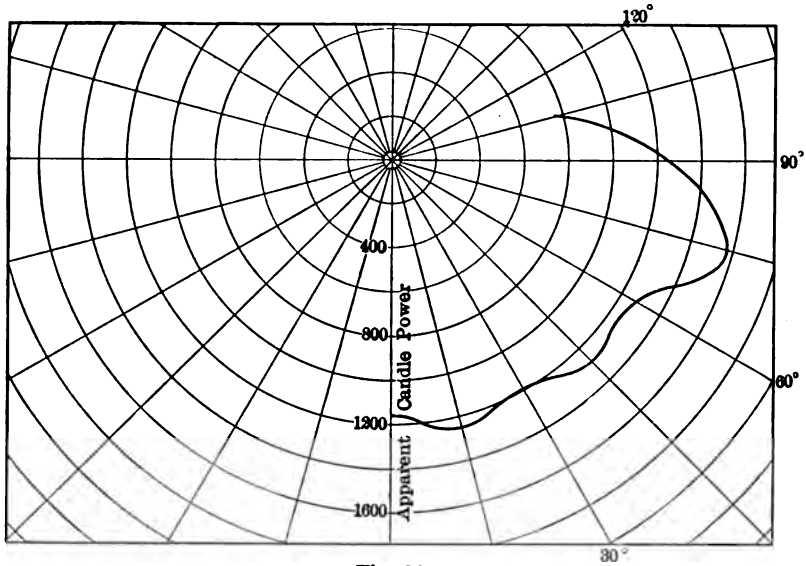


Fig. 86.

material is, as already indicated, of very different character. The best-known form of luminous arc is the so-called magnetite arc, in which the lower (negative) electrode consists of an iron tube packed with a mixture of magnetite, titanium oxide, and sometimes small quantities of chromium oxide. Approximately 75 per cent of the mixture is magnetite and nearly all the rest titanium oxide. Magnetite is a pretty fair conductor, vaporizes easily, giving a good volume of vapor in the arc, and while by itself it is not a very efficient illuminant, it serves as an effective carrier for the titanium, to which much of the brilliancy of the arc is due.

Titanium oxide by itself is a bad conductor, vaporizes with considerable difficulty, and slags abominably, so that it is impracticable to use a large percentage in connection with the magnetite.

The mixture is quite sensitive, in light-giving properties and steady-burning quality, to small changes of composition. The positive electrode, commonly the upper one, although in lamps of some makers the position is reversed, is a short copper cylinder which burns away very slowly and does not visibly color the light. The arc stream is most intense near the surface of the negative electrode, and the light falls away considerably toward the positive.

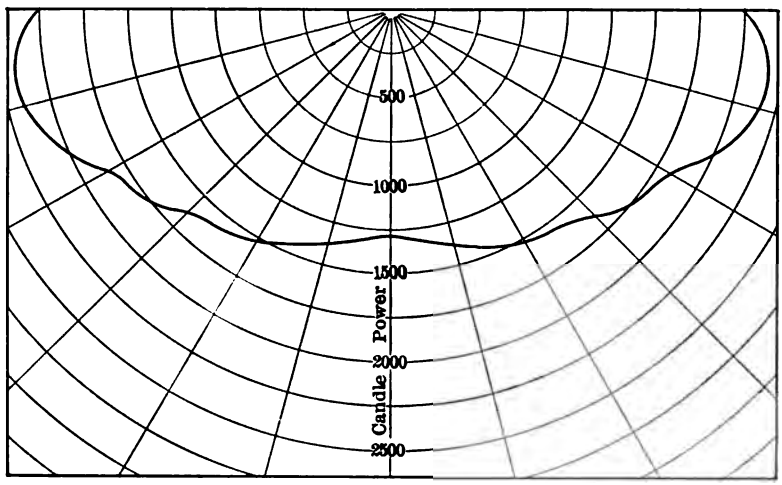


Fig. 87.

Neither electrode gives any material amount of light by incandescence. The shape of the arc stream causes the magnetite lamp to give an exceptionally large proportion of its light at or near the horizontal, and it is usually worked with a reflector to turn downward some of the beams which would naturally pass above the horizontal. It has a distribution, therefore, most convenient for street lighting, for which it has come into very great use. The magnetite lamp is made for the most part in two sizes, one taking about 4 amperes and the other about 6.6 amperes; and the lamps are usually worked in series, either from arc-light generators or more commonly from mercury rectifiers.

Fig. 88 shows the distribution curve of the ordinary 4-ampere magnetite lamp furnished with the commonly employed five-eighths-inch magnetite lower electrode. This lamp took about 310 watts and gave 467 mean lower hemispherical candle power and 237 mean spherical candle power. The specific consumption, therefore, was 0.66 watt per candle for the former case and 1.31 watts per candle for the latter. This performance was with a clear globe frosted on the bottom and fitted with the usual ash pan below the lower electrode. The life of the electrodes in such a lamp is from 150 to 200 hours. The performance shown in this curve is a thoroughly typical one of average performance. The shape of the curve is a good one for street lighting, but arcs of this character give so tremendous a glare that it is better to

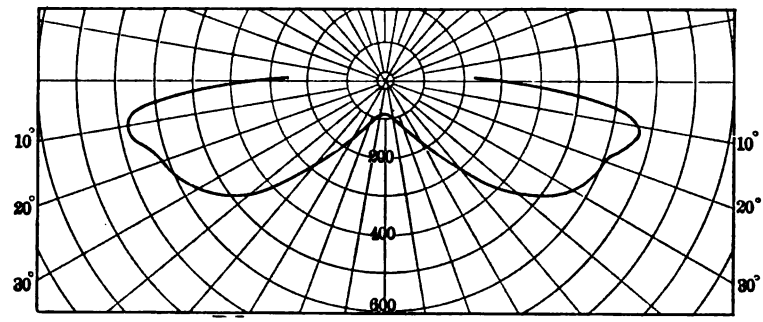


Fig. 88.

sacrifice something of the light and use opal globes with them when employed in a thickly settled district or where the traffic under them is considerable.

Fig. 89 shows the corresponding performance of a series magnetite lamp worked at 6.6 amperes. This lamp was equipped with a clear globe and the lower electrode was a half-inch stick giving a burning life of about 60 hours. The electrode was a particularly good one from the standpoint of efficiency, as the result shows. It should be clearly understood that in the case of luminous electrodes of all kinds much depends on the rate of combustion of the light-giving material. If the electrode composition is planned to give a long life, it will, other things being equal, give a lower efficiency, and vice versa. This 6.6-ampere lamp took 510 watts while giving 1472 mean lower hemispherical

candle power and 809 mean spherical candle power. The specific consumption in the former case was 0.35 watt per candle and in the latter 0.63.

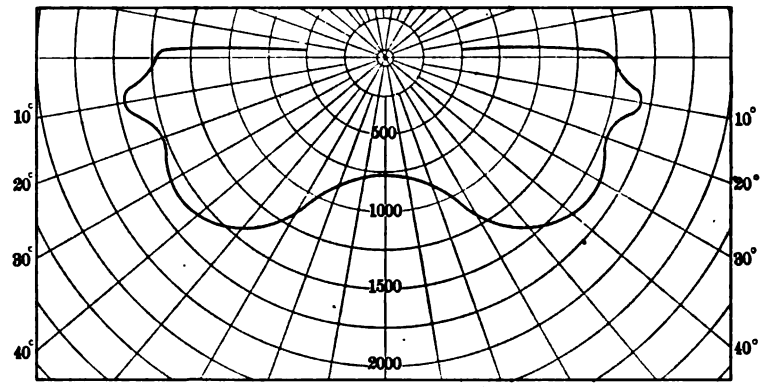


Fig. 89.

On this very powerful lamp a diffusing globe is even more necessary than in the case of the smaller lamp. Fig. 90 shows a distribution curve of the same lamp in a fairly light opal globe.

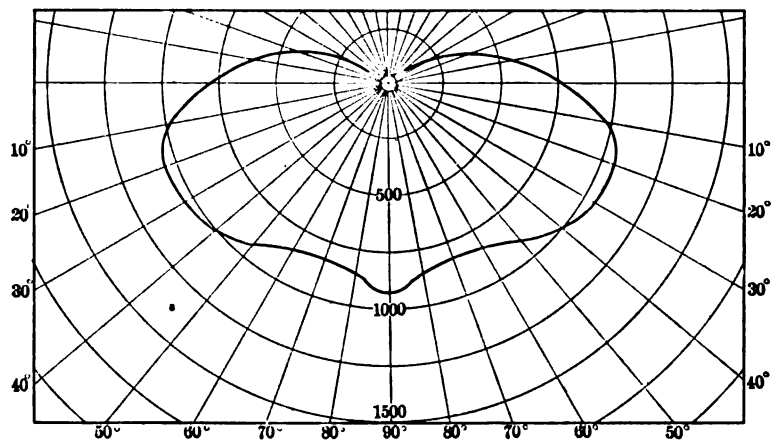


Fig. 90.

As will be seen at a glance, the presence of the globe cuts down the light very considerably, the mean spherical candle power being reduced 23 per cent. The curve is rounded by the diffusion and the maximum drops a little further below the horizontal. The

distribution is still excellent, however, and for first-class street lighting the lamp with the opal globe is much preferable to that with the clear globe. The watts taken were 510 as before, but the mean lower hemispherical candle power was reduced to 968 and the mean spherical candle power to 622. The specific consumptions were respectively 0.53 and 0.82 watt per candle.

The chief difficulty with magnetite lamps is the production of a quantity of brown oxides which have to be disposed of to keep them from settling on the globe and clogging the mechanism. This is done by a central draft tube through the lamp, which under ordinary circumstances carries out the fumes pretty successfully. Sometimes in hot and damp weather they give trouble by sticking to the upper electrode, causing the arc to burn unsteadily, and by depositing a brown smudge over the inside of the globe. These lamps, therefore, require some extra care in keeping the globes clean, but in spite of such drawbacks the magnetite arc is at the present time the best powerful illuminant available for outdoor use in this country.

The earlier lamps gave a good deal of trouble both with the mechanism and by formation of slag and welding of the electrodes, but these difficulties have gradually been overcome, until at the present time the trouble from lamps being out is no more than it was in the case of the earlier carbon lamps.

From the standpoint of economy and efficiency, the carbon arc has little reason for use as compared with the 6.6-ampere magnetite arc. The 4-ampere magnetite arc is considerably less efficient than the larger size, but still admirably suited for exterior lighting. Unfortunately, the magnetite arc cannot be used on alternating current, and if only alternating current is available it must be rectified before use.

A very interesting attempt to get around this difficulty is furnished by the titanium-carbide arc, which at one time promised to come into considerable use. This lamp was adapted for alternating current only, carried a carbon upper electrode about one inch in diameter, and had as lower electrode an iron tube which was packed with the titanium-carbide mixture. This lamp was especially adapted for use on low currents, the ordinary type taking only 2.5 amperes and 180 watts. So admirable was the titanium mixture in light-giving power that the efficiency even of this small arc ran very high, the specific consumption per mean lower hemi-

spherical candle power being between 0.4 and 0.5 watt, and the distribution resembled very much that of the magnetite arc. Unfortunately, the titanium electrode produced a frightful smudge of brown oxide when the current was pushed materially above the figure just stated, so that ventilation became a very serious matter; and when the lamp was kept to 2.5 amperes or thereabouts it became hypersensitive to small variations in current and irregularities of voltage, so that at the present time this interesting and rather promising illuminant is making very little headway. It is greatly to be hoped that the difficulties met in its development may be overcome, because so efficient a lamp employing alternating current would be of very great value to the art if reduced to a thoroughly practical form.

We now come to a totally different class of illuminants, more akin to arcs than to incandescents in their physical properties, and hence classified with arcs, but yet radically different from arcs of ordinary type, in that the arc stream is produced in sealed tubes and the light is given by relatively long columns of vapor or gas, not subject to oxidation, and at comparatively moderate temperature. The best known of these illuminants is the Cooper-Hewitt mercury-vapor lamp, which has now come into extended use for the illumination of large areas. In this lamp a long glass tube containing a small amount of mercury is supplied with current through platinum leading-in wires, one of which dips in the mercury and the other of which is attached to an iron electrode. The mercury is the negative electrode and when the arc is once started, as it can be very conveniently by momentarily tilting the tube so that the mercury runs into contact with the iron electrode and then withdraws, it fills the whole interior of the tube with glowing mercury vapor and gives out a very brilliant and steady light.

Fig. 91 shows one of the commonest forms of Cooper-Hewitt lamp with its complete mounting. The upper part of the lamp contains inductance coils, an adjustable resistance, an automatic tilting magnet, and, in case of lamps operating in series, a shunt resistance and a cut-out. The lamp shown takes 192 watts at the terminals, the normal current being 3.5 amperes. The light-giving tube is about 22 inches in length between the bulbs and of about 1 inch bore. The mercury electrode is contained in the blackened bulb at the right of the illustration, the blackening being for the

purpose of preventing the boiling and bubbling of the mercury in the bulb from making itself visible as a flicker.

This particular size of lamp is intended to be operated two in series on the 110-volt circuit. For use singly on 110 volts, tubes of slightly more than double the length are used. When the current is thrown on the lamp is tilted, and, dropping back, starts the arc, which, at first curiously bluish, comes in a minute or so to intense brilliancy and acquires a greenish cast. The light is that of the



Fig. 91.

mercury spectrum, which for light-giving purposes consists of three intense lines in the yellowish and green, reënforced by a vivid blue-violet line which is momentarily predominant when the arc first starts. Red is practically absent from the spectrum, the only red lines being too faint to produce any noticeable effect.

Though the resulting color of the light is somewhat ghastly and plays curious tricks with colors containing red, the lamp is very powerful and steady, of moderate intrinsic brilliancy, — some 10 to 11 candle power per square inch, — and from its being approximately

monochromatic is particularly effective for seeing details in black and white. Visual acuity for ordinary reading and writing purposes is considerably enhanced under the mercury light, so that its usefulness for such seeing is materially greater than its nominal candle power would indicate. Its efficiency, however, is high, the tube of Fig. 91 being rated at about 300 mean lower hemispherical candle power including the reflector, which implies a specific consumption of 0.6 to 0.7 watt per candle. The Cooper-Hewitt lamp is also available for alternating current, for use with which a small individual rectifier is added to the auxiliary apparatus. The tube has a life running to many hundred hours under favorable circumstances and if not pushed above its rated current.

An extremely interesting and very recent development is the use in connection with this lamp of a fluorescent reflecting screen devised by Dr. Hewitt, which adds to the light the red rays absent from the original mercury spectrum. In other words, the fluorescent reflector transforms part of the incident light into red and orange light, and with a sufficient area of reflector the result is a pretty good white. A similar result has been reached by using in connection with the mercury tube a certain proportion of ordinary incandescent lamps to supply the red rays, but the fluorescent screen is an equally efficient and much more elegant solution of the difficulty.

A still more interesting and valuable illuminant is the quartz-mercury lamp, which is essentially the same thing as the mercury-vapor lamp just described, except that it is worked intensively in a tube of fused quartz, which is sufficiently refractory to be safely worked at high current density and greatly enhanced temperature. Such lamps have come into considerable use abroad and promise some very striking developments.

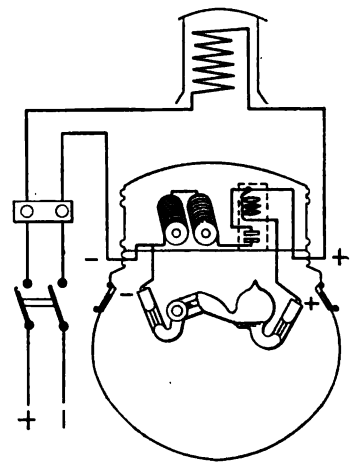


Fig. 92.

Fig. 92 shows in diagram the arrangement of a quartz lamp as manufactured by the Westinghouse-Cooper-Hewitt Company in England. The quartz tube is carried in a clear-glass globe sur-

mounted by a small housing containing the ballast resistance, tilting magnet, and cut-out, the operation of the lamp being practically as already described for the ordinary mercury-vapor lamp. The tube is of clear fused quartz, consisting of a terminal bulb of mercury at each end, connected by a vapor tube three or four inches long, in which the light is produced.

Such lamps are adapted to work on either 110- or 220-volt circuits taking about 3.5 to 4 amperes. They give a very intense bluish-white light which, unlike that of the ordinary mercury-vapor tube, contains a perceptible amount of red radiation, although not enough to give reds their full value when viewed under it. The light is very steady and the tube holds up for a very long life stated at something like 2000 hours on the average. The efficiency is

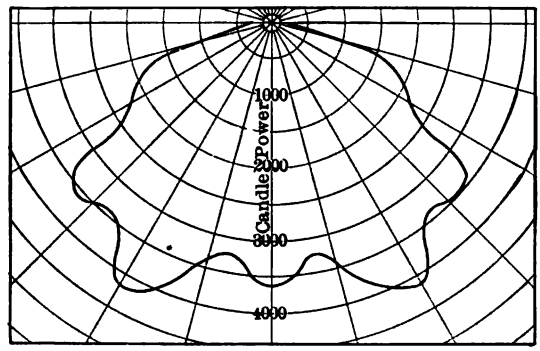


Fig. 93.

very high, but varies somewhat from tube to tube, depending largely on the current density to which the lamp is forced.

Fig. 93 shows the result of a test, made by the author, of a quartz-mercury lamp from one of the Continental makers, in which the volts at the terminal of the lamp were 224, the amperes 3.5, and the mean lower hemispherical candle power 2310, which corresponds to a specific consumption of 0.295 watt per mean lower hemispherical candle power. This curve was the mean of the results by three observers, all of whom were in close agreement. The sinuosities are probably due to the effect of the globe and the reflector and appeared in all the readings.

Some tests run higher and some lower than the figures here given, which may be regarded as a fair average result. The light of the quartz-mercury arc is remarkably rich in extreme ultra-violet

radiations, which are, however, completely cut off by the inclosing glass globe, though they make themselves manifest within it by a strong smell of ozone.

There has been some rather unnecessary fear of the quartz arc as an illuminant on account of the fact that extreme ultra-violet rays are known to react unpleasantly on the skin and particularly on the eyes, but the glass globe cuts off these injurious radiations just as it does in the case of the magnetite and other powerful electric arcs which are also rich in the same radiations, so that, practically, the lamp is no more to be feared than any other source of very intense light and, actually, for a given illumination, delivers as little ultra-violet energy as any known illuminant.

Its high efficiency, great steadiness, and permanency should give it a high place among practical illuminants when the quartz tubes are more readily obtainable. At the present time they are produced only by a few makers, so that the quartz lamp is only recently a regular commercial article in this country.

Finally, one comes to a still different class of gaseous illuminant in which the electric discharge takes place in a column of some rarefied permanent gas. This type of lamp has often been suggested but has been produced commercially only in the form of the Moore tube, which is in some use and represents an exceedingly interesting development of gaseous illuminants. The Moore tube is essentially a long Geissler tube fed by an individual high-tension transformer coupled directly to the tube so that no high-tension wiring is exposed. The tube is generally $1\frac{1}{2}$ inches to $1\frac{3}{4}$ inches in diameter and in length many feet — up, indeed, to several hundred. The tube forms a closed loop running about the area to be illuminated and itself serves practically as the secondary of the transformer circuit.

Fig. 94 shows in diagram the arrangement of the apparatus. The transformer is inclosed in a box entered by the terminals of the tube. The primary winding is connected to any convenient source of alternating-current supply of 60 cycles or so, and in series with it is the regulating valve, which is a very essential and interesting portion of the apparatus.

As is well known, the conductivity of a column of gas increases rapidly up to a certain point with diminution in pressure. The point of maximum efficiency for the Moore tube is about 0.1 millimeter of mercury, while the maximum conductivity of the gas

is reached at about 0.08 millimeter pressure. As the tube continues in use the pressure in it decreases, and, with no means for regulating the vacuum provided, would reach a point which would gradually put the tube out of action. To avoid this difficulty a branch tube leading to both sides of the lighting tube is turned upward at the end and inclosed by a slender conical plug of porous carbon, which in the normal action of the tube is just covered by mercury. A small solenoid in series with the primary circuit is

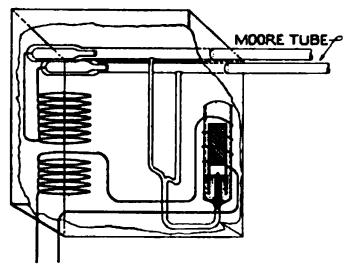


Fig. 94.

provided with a core which carries a glass displacing tube, which with the normal current in the lighting tube rests in equilibrium with the tip of the carbon cone just covered. When the vacuum falls below 0.1 millimeter and approaches the critical point of conductivity, there is a slight increase of the current through the tube, which lifts the displacer, uncovers the tip of the cone, and lets gas filter in until the normal vacuum is restored.

The gas thus fed can be ordinary air when the tube is left open, or any convenient gas, a supply of which may be connected with the inlet tube of the valve. Ordinary air gives a slightly pinkish light; nitrogen, which gives a higher efficiency and is more commonly used, gives a more yellowish tint; and when a nearly white light is desired the gas employed is CO_2. The color given by the CO_2 tube in fact is a pretty close approximation to white, considerably bluer than direct sunlight, but less blue than the light of a bright-blue sky.

The efficiency of the tube as a light producer has been subject to considerable study. It is a mistake to suppose that the light given by an electrical discharge through gases is necessarily efficient; in fact it varies enormously in efficiency according to the

particular characteristics of the spectrum given by the gas. The nitrogen tube, which is that most commonly employed, has been found by several experimenters to give a specific consumption of approximately 2.4 watts per mean spherical candle power; while the CO_2 tube as used, especially for color-matching purposes, generally in short lengths, has a specific consumption under these conditions of at least 6 or 8 watts per candle. The nitrogen tube has, therefore, a slightly greater actual efficiency than the tantalum lamp and materially less than the tungsten lamp. The intrinsic brilliancy of the tube, about 0.4 to 0.5 candle power per square inch, and the even distribution given by its great extent, are practical considerations which tell in its favor. The life of the tubes, barring accidents, is very long, running certainly to many thousand hours; indeed, it is a little uncertain what except accident would limit the life, although in time the interior surface of the tube would probably be affected. Very recently tubes filled with the rare gas neon have been tried abroad. The color is a beautiful orange and the specific consumption is stated to be about 0.8 watt per candle power, a figure far lower than with any other gas yet tried.

This closes the story of practical illuminants operating by the electrical discharge. The list of those unmentioned here would be a long and somewhat interesting one, but unprofitable to recite from the standpoint of practical illumination.

CHAPTER IX.

SHADES AND REFLECTORS.

As has already been pointed out, the illuminants in common use leave much to be desired in the distribution of light, and have, for the most part, too great intrinsic brilliancy. The eye may suffer from their use, and even if this does not occur the illumination derived from them is less useful than if the intrinsic brilliancy were reduced.

Hence the frequent use of shades and reflectors in manifold forms. Properly speaking, shades are intended to modify the light by being placed between it and the eye, while reflectors are primarily designed to modify the distribution of the light rather than its intensity. Practically, the two classes often merge into each other or are combined in various ways.





Figs. 95 and 96. — Cut-glass Stalactite and Globe.

There is, besides, a considerable class of shades of alleged decorative qualities, which neither redistribute the light in any useful manner nor shield the eye to any material degree. Most of them are hopelessly Philistine, and have no æsthetic relation to any known scheme of interior decoration. Figs. 95 and 96, a stalactite and globe, respectively, of elaborately cut glass, are excellent examples of things to be shunned. Cut glass is not at its best when viewed by transmitted light, and neither diffuses nor distributes the light to any advantage. Such fixtures logically belong over an onyx bar inlaid with silver dollars, and to that class

of decoration in general. Almost equally bad are shades that produce a strongly streaked or mottled appearance, like Figs. 97 and 98. These neither stop the glare from a too intense radiant nor render the illumination more practically useful by improving its distribution. These shades happen to be for incandescent lamps, but they are evil in both principle and application, and would be equally bad in connection with any other kind of illuminant.

With open gas flames a shade may be of some use as a protection from draughts, but generally its purpose is to improve the illumination, and if it fails of this it has no excuse for being. For artistic reasons it is sometimes even desirable to reduce the illumination to a deep mellow glow quite irrespective of economy, and in such case shades may be made ornamental to any degree and of any



Figs. 97 and 98. — Shades to Avoid.

density required, or lights may be distributed for purely decorative purposes, but gaudy spotted and striped affairs, like those just shown, are useless even for these ends. If for decorative purposes economy is deliberately set aside, the honest decorator will say so frankly. There is no excuse, however, for selling a man shades or fixtures certain to double his lighting bill if he tries to get an adequate amount of light, while keeping him in ignorance of their inefficiency.

The first requirement of a shade is that it shall actually soften and diffuse the light it shelters. If it does not do this, no amount of ornamentation can make it tolerable from an æsthetic standpoint. Almost any kind of ornamentation is permissible that does not defeat this well-defined object. Translucent porcelain, ground and etched glass, are all available in graceful forms. If perfectly plain shades, like Fig. 99, seem too severe, then those finely etched in inconspicuous figures, like Figs. 100 and 101, may

answer the purpose. In such shades the shape is purely a matter of taste, subject always to the requirement that the bright source must be hidden from all probable points of view. The main thing is to conceal the glaring incandescent filament or mantle so that it will not show offensively bright spots. Hence the general objection to cut glass, which, if used at all, should for the display of its intrinsic beauty be so arranged that it can be seen by strong reflected light rather than by that which comes from its interior.

Thin paper and fabrics may be most effectively employed for shades and can readily be made to harmonize with any style of ornamentation or color scheme that may be in hand. In this respect such materials are far preferable to glass or porcelain, although more perishable and less convenient for permanent use on a large scale. They also entail much loss of light, and are far better suited to domestic illumination than to larger installations.



Figs. 99, 100, and 101. — Shades.

The real proportion of light cut off by decorative shades has not, to the author's knowledge, ever been accurately measured, and, indeed, by reason of the immense variety in them, it would be almost impossible to average. It is safe to say, however, that it is generally over 50 per cent, although the light is so much softened that the loss is not seriously felt in reading or in other occupations which do not tax the eyes severely.

With respect to porcelain and glass shades the proportion of light absorbed has been measured many times, and on many different kinds of shades, so that actual, even if diverse, figures are available. The following table gives the general results obtained by several experimenters on the absorption of various kinds of globes, especially with reference to arc lights:

	Per cent.
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60

The great variations to which these absorptions are subject are evident enough from these figures. They mean, in the rough, that clean clear-glass globes absorb about 10 per cent of the light, and that opalescent and other translucent glasses absorb from 15 to 60 per cent, according to their density. Too much importance should not be attached to this large absorption, since it has already been shown that in most cases, so far as useful effect is concerned, diffusion and the resulting lessening of the intrinsic brilliancy are cheaply bought even at the cost of pretty heavy loss in total luminous radiation.

The classes of shades commonly used for incandescent lamps and gas lights have been recently investigated with considerable care by Mr. W. L. Smith, to whom the author is indebted for some very interesting data on this subject.

The experiments covered more than twenty varieties of shades and reflectors, and both the absorption and the redistribution of light were investigated. One group of results obtained from 6-inch spherical globes, intended to diffuse the light somewhat generally, was as follows, giving figures comparable with those just quoted:

	Per cent.
Ground glass	24.4
Prismatic glass	20.7
Opal glass	32.2
Opaline glass	23.0

The prismatic globe in question was of clear glass, but with prismatic longitudinal grooves, while the opal and opaline globes were of medium density only.

Etched glass, like Figs. 100 and 101, has considerably more absorption than any of the above, the etching being optically equivalent to coarse and dense grinding. Their diffusion is less homogeneous than that given by ordinary grinding, so that they may fairly be said to be undesirable where efficiency has to be seriously considered.

A plain, slender canary stalactite behaved like the globes as respects distribution, and showed just the same absorption as the ground-glass globe, i.e., 24.4 per cent, but permitted an offensively brilliant view of the filament within.

Another group of tests had to do with reflecting shades designed to throw light downward, in some cases giving a certain amount of transmitted light, in others being really opaque. The char-

acteristics of some common forms of such shades are plainly shown by the curves of light distribution made with the shades in place. Figs. 102 and 103 show two thoroughly typical examples of these shades. Fig. 102 is the ordinary enameled tin 8-inch shade, green



Fig. 102. — Conical Shade.



Fig. 103. — Fluted Cone.

on the outside and brilliant white within, a form too often used over desks. Fig. 103 is almost as common, being a fluted porcelain 6-inch shade, used in about the same way as Fig. 102. Figs. 104 and 105 give the respective vertical distributions produced by

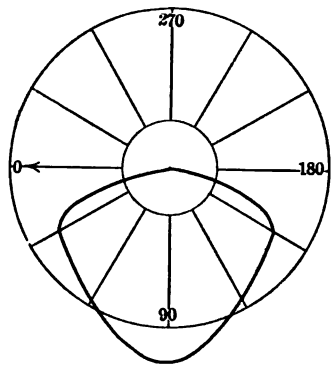


Fig. 104. — Distribution from Fig. 102.

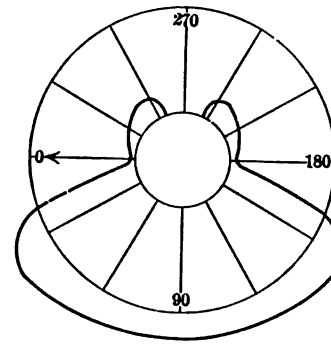


Fig. 105. — Distribution from Fig. 103.

these two shades, the outer circles showing for reference the nominal 16-candle-power rating. The porcelain not only gives a more uniform reflection downwards, but transmits some useful light outwards. The case as between it and the tin shade of Figs. 102 and 104, which gives a strong but narrow cone of light downward, may be tabulated as follows:

	8-inch Tin Enameled.	6-inch Fluted Porcelain.
Mean spherical candle power	8.12	9.89
Maximum candle power	29.49	18.15
Horizontal candle power	0.00	5.26
Absorption, per cent	28.1	12.4

The absorption is, of course, based, as elsewhere, on the mean spherical candle power. Of these two shades the porcelain one is considerably the better for practical purposes. Although it gives a somewhat smaller maximum candle power directly below the lamp, it gives a much larger well-lighted area, and is for every reason to be preferred. A still better form of shade is a plain opal-glass cone flashed with green glass on the outer surface. The unaltered vertical distribution of an incandescent lamp is given in the curve shown in Fig. 56, p. 124, and that curve was from the same lamp used in testing these shades.

It should be noted that the relations of these two forms would not be materially altered if they were of appropriate size and were applied to Welsbach burners, the distribution of light from which bears a rather striking resemblance to that from an incandescent



Fig. 106. — Shallow Cone.



Fig. 107. — McCreary Shade.

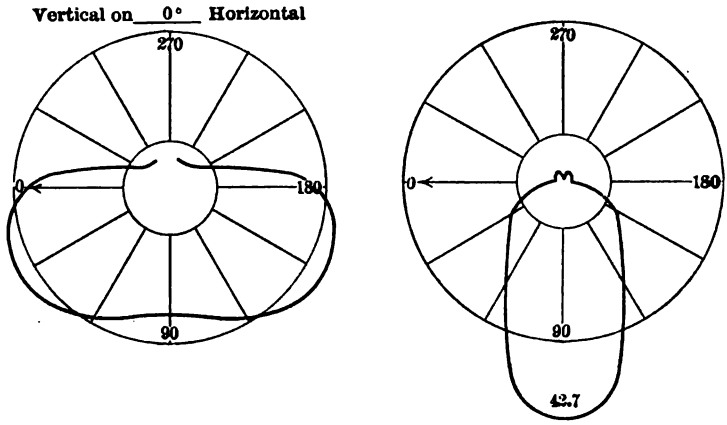
lamp. The tin shade gives too much the effect of a bright spot to be really useful for most purposes. If such a concentrated beam is desired, it is far better obtained by other and more perfect methods.

Figs. 106 and 107 show two other forms of reflecting shade in somewhat common use, the former designed to give the light a general downward direction, the latter to produce a strong and uniform downward beam. Fig. 106 is a 6-inch fluted porcelain shallow cone, while Fig. 107 is the well-known and excellent McCreary shade, 7-inch. They are intended for widely different purposes, which come out clearly in the curves of distribution, Figs. 108 and 109.

The flat porcelain cone, Fig. 108, merely gathers a considerable amount of light that would ordinarily be thrown upward, and scatters it outwards and downwards. It has a generally good effect

in conserving the light, and whether applied to an incandescent lamp or a Welsbach deflects downward a good amount of useful illumination, but is objectionable in that it does not hide the lamp. All the rather flat so-called "distributing" shades should generally be shunned for this reason.

The McCreary shade, on the other hand, is deliberately intended to give a rather concentrated beam, softened, however, by the ground-glass bottom of the shade. As Fig. 109 shows, it accomplishes this result quite effectively, giving a powerful and uniform



Figs. 108 and 109. — Curves of Distribution.

downward beam. The annexed table shows in a striking manner the difference in the two cases:

	Flat Porcelain Cone.	McCreary.
Mean spherical candle power.....	9.84	7.50
Maximum candle power.....	15.72	42.72
Horizontal candle power.....	13.94	2.29
Absorption, per cent.....	12.8	33.5

The small nominal absorption in the first instance is merely due to the fact that the shade is not reached by any considerable portion of the light, while the large absorption in the later case only indicates that nearly the whole body of light is gathered by reflection, and sent out through a diffusing screen.

The porcelain cone is irremediably ugly, but a less offensive shade having the same general properties may sometimes be put to a useful purpose. The McCreary shade is purely utilitarian, but

neat, and does its work well in producing a strong, directed illumination — a bit too concentrated, perhaps, for ordinary desk work, for which it should be fitted with a lamp of 8 or 10 candle power, but very useful for work requiring unusually bright light. Of fancy shades modified in various ways there are a myriad, usually less good than the examples here shown.

In cases where concentration of light downwards along the axis of the lamp is desirable, rather efficient results are attained by combining lamp and reflector, that is, by shaping the bulb of the lamp itself so that when the part of it nearest the socket is *silvered* on the outside it shall form an effective reflector of proper shape. Obviously when the lamp burns out or grows dim the whole combination becomes useless, in which respect the device is less economical than an ordinary lamp in a carefully designed reflecting shade like the McCreary. On the other hand, the reflector lamps are, on the whole, somewhat more efficient during their useful life, and for general purposes of illumination are much less obtrusive.

In such lamps the bulb, instead of being pear-shaped, is spherical or spheroidal, with the upper hemisphere silvered, the silvering being protected by a coat of lacquer. The filament usually has several convolutions of rather small radius, so as to bring as large a proportion of the incandescent filament as possible near to the center of the bulb. A filament so disposed throws an unusual proportion of the light upwards and downwards when the lamp is mounted with its axis vertical, but, of course, at the expense of the horizontal illumination.

For various illuminants shades require to be somewhat modified in form, and an enormous variety of shades and reflectors are on the market, of which those here described may serve merely as samples. Shading the radiant, whatever it may be, is a simple matter, and so is the use of a pure reflector to direct the light in any particular direction. But the commonest fault of powerful radiants, as we have already seen, is too great intrinsic brilliancy, which calls for diffusion, and good diffusion without great loss of light is difficult of attainment, particularly if at the same time there is need of redistributing the light so as to strengthen the illumination in any particular direction.

By far the most successful solution of this troublesome problem is found in the so-called holophane globes, devised a few years ago

by MM. Blondel and Psaroudaki, and now in extensive use both here and abroad. The general principle employed by these physicists was to construct a shade of glass so grooved horizontally as to form the whole shade of annular prisms. These are not formed as in a lighthouse lens, to act entirely by refraction, because in the attempt to bend the rays through a large angle by refraction alone there is a large loss.

The prisms of the holophane globe are relieved, as it were, at certain points, so that rays which need to be but little deflected are merely refracted into the proper direction, while those that must be greatly bent to insure the proper direction are affected by

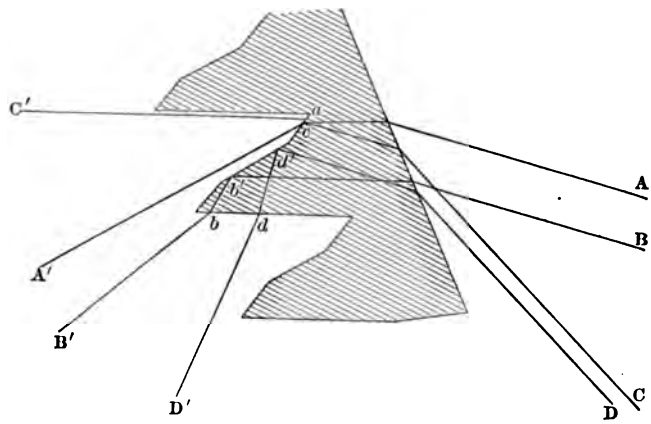


Fig. 110. — Section of Holophane Globe.

total reflection. This combination of refracting and reflecting prisms in the same structure accomplished the efficient redistribution of the light in a very perfect manner. The diffusion remained to be effected, and the means adopted was to form the interior of the globe into a series of rather fine, deep, rounded, longitudinal grooves.

The total result is a great reduction of the intrinsic brilliancy, coupled with almost any sort of distribution required, the total loss of light meanwhile being less than in any other known form of diffusing shade or reflector. Fig. 110 shows in detail, considerably magnified, the structure of the holophane prisms and the combination of refraction and reflection that is their characteristic feature. Here the ray *A* is merely refracted in the ordinary way, emerging

with a strong downward deflection from the prism face in the direction A^1. Ray BB^1 is totally reflected at the face b^1, and then refracted outwards at b. C is strongly refracted and emerges from the surface c, while DD^1 is refracted at entrance, totally reflected at d^1, and again refracted at emergence from d.

The net result is to keep in this particular form of prism surface nearly all the rays turned downward below the horizontal. Obviously other prismatic forms might be employed, which would give a very different final distribution, but the principles involved are the same.

Fig. 111 shows, likewise on a greatly enlarged scale, the interior fluting which accomplishes the necessary diffusion of light. The

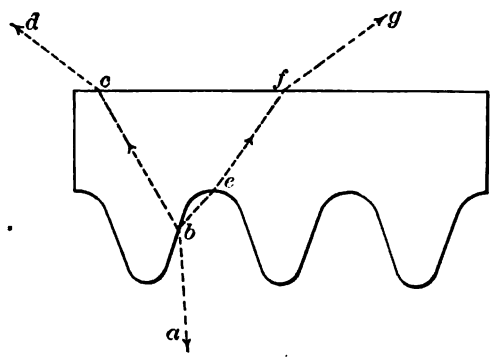


Fig. 111. — Diffusing Curves of Holophane.

ray a is here split up into a reflected component, afterwards refracted — b, e, f, g, and a purely refracted component, b, c, d. The shape of the flutings is such as by this means to secure excellent diffusion at a very small total loss of light. The inner and outer groovings, being at right angles, produce a somewhat tessellated appearance, but aside from this the surface is quite uniformly illuminated.

These holophane globes are made for all kinds of radiants, but are most commonly applied to Welsbach gas burners and to incandescent electric lights. Evidently the shape of both grooves and globe must vary with the purpose for which the shade is desired, which results in a very large number of forms, from which a selection may be made for almost any variety of illumination.

It should be noted that these holophane shades both diffuse and

redistribute the light in a very thorough manner. Speaking generally, they are of three distinct classes. The first is laid out according to the general principles of Fig. 110, and is intended to direct most of the light downwards, serving the same end as a reflector, but giving at the same time some needful diffusion without the use of a ground or frosted globe. The general results are strikingly shown in Fig. 112, which gives a graphic idea of what such a globe actually does.

The second class of globes has for its purpose a fairly uniform distribution of the light, mainly below the horizontal, and it is



Fig. 112. — Holophane, Downward Distribution.

intended for ordinary indoor lighting, where a particularly strong light in any one direction is needless. Its effect is shown in Fig. 113. The third general form of holophane globe is designed for the especial purpose of throwing a strong light out in a nearly horizontal direction, and is shaped so as thus to redistribute the light, putting it where it is most useful for such work as street lighting, large interiors, and the like. The effect produced is admirably shown by Fig. 114. The shapes of globes shown in these last three figures are those intended for mantle burners.

In general, the device enables a good degree of diffusion to be secured together with almost any peculiarity of distribution that

could be wanted, and with a degree of efficiency unexcelled by any known system of shades or reflectors, unless it be the Fresnel lighthouse lenses.

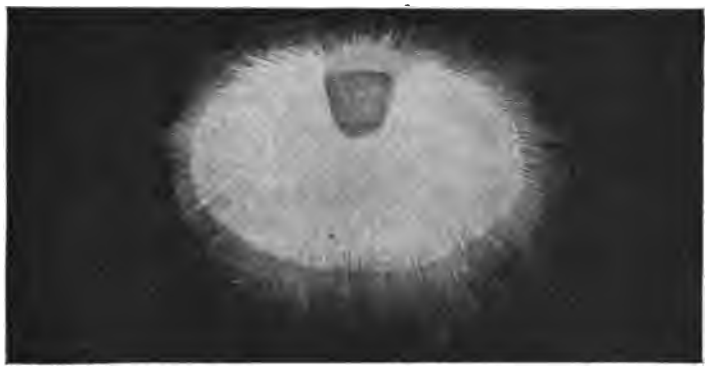


Fig. 113. — Holophane, General Distribution.

One does not generally get such a combination of good qualities without certain disadvantages that must be taken in partial compensation. In the holophane system the weak point is dirt. The doubly grooved surface makes an excellent dust catcher, and a layer of dust can easily be accumulated quite sufficient to cut down the efficiency very seriously. And, moreover, a hasty dab with a



Fig. 114. — Holophane, Outward Distribution.

rag does not clean a holophane globe; it must be gone over carefully and thoroughly. When kept clean, the globes actually will do just what is claimed for them, and are not at all a merely theoretical development excellent only on paper, but they *must* be kept clean, and should not be used where they cannot or will not receive proper attention.

This is probably the chief reason, aside from the extra cost, why such globes have not been more extensively used for street lighting, to which their power of redistributing the light in the most useful direction admirably fits them. The results obtained in tests of these globes are so striking as to merit examination in some detail.

In spite of the trouble from dust, the holophane globes have come into considerable use for street lighting in some European cities, notably Munich, where several thousand have been used on Welsbach street lamps for several years past. The net results are reported to be exceedingly good, although the amount of labor involved must be, from an American standpoint, large. Breakage in this case is reported at about 10 per cent per annum.

If this device could be successfully applied to arc lamps for street lighting, a very valuable redistribution of the light might be effected, but certain obstacles seem to be interposed on account of the shifting of the arc as the carbons are consumed. With a focusing form of lamp this trouble would be averted, but such lamps have been little used here until the recent advent of the flame and luminous arcs which give fumes likely to be troublesome. With inclosed arcs, however, it should be possible to use such globes with fair success.

More recently an interesting modification of the holophane idea has been applied to the construction of prismatic reflectors, which have come into very large use. The prismatic reflector is essentially a somewhat bowl-shaped structure of clear pressed glass, smooth on the inside, and on the outside formed into a series of right-angled prisms, running longitudinally. These prisms act by total reflection, returning the light that falls upon them inward and downward, so that the reflector acts as though it were provided with an exceedingly good reflecting surface.

Fig. 115, which shows a section of the wall of such a prismatic reflector, exhibits the prismatic action. The ray A passes through the clear inner surface, strikes one of the outer prismatic surfaces at B, is totally reflected to C, and then is totally reflected again, and is thus bent back on itself. If the incidence at B were in the plane of the paper, the emergent ray would be parallel with the entering one. As the rays from the source are generally not in what corresponds to this plane, the emergent ray is usually shifted downward so that it passes out of the reflector. Obviously, by

changing the shape of the prismatic reflector this shifting of the rays can be controlled so as to modify the distribution. It thus is possible to duplicate the types of distribution already shown for the holophane globes, while using a reflector open at the mouth and thus relieved of any absorption of such light as would naturally pass freely out of its aperture.

The advantage gained by this arrangement is the reduction by a material amount of the dust difficulty to which reference has been made. The interior of the reflector is smooth and does not collect dust freely. The dust falling on the exterior surface is not in optical contact with the glass, and hence does not interfere with the total reflections. Such a reflector is not, however, completely opaque when viewed from the outside, but diffuses a

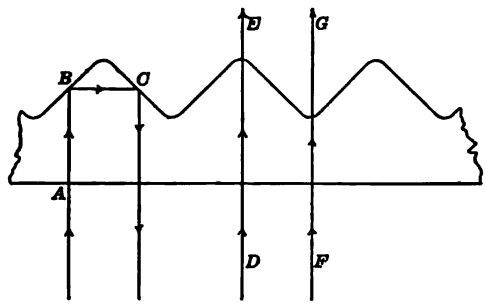


Fig. 115.—Showing Principle of Prismatic.

moderate amount of light which usefully illuminates the surrounding space. This is chiefly due to the fact that the angles of the prisms cannot be made absolutely sharp, and consequently rays which strike the apex of the prism as *D*, or the junctions of two prisms as *F*, do not strike at any totally reflecting angle and hence pass through as *E* and *G* respectively. When more, and more uniform, diffusion is wanted than is readily provided in this manner, the exterior or interior surfaces can be very finely etched or covered with a film of enamel. In such case a large part of the light is still totally reflected, but the proportion passing through is materially increased, so that the reflector has a soft diffusing surface while yet serving as an efficient reflector. This diffusion is ordinarily secured by a very delicate acid etching of the exterior surface, and many reflectors of this so-called "satin-finished" type are in use. They are preferable to the plain re-

flectors, where the reflector is in full view, since the latter, as shown by the diagram, tends to show its diffusion in rather bright streaks along the angles of the prisms.

The best way of examining the performance of these or other reflectors is to put a lamp attached to a flexible cord in the reflector and have an assistant hold it and swing it slightly from side to side while it is under observation from a distance of a few yards. It is then easy to see from the appearance of the reflecting surface whether the light is being widely scattered, moderately concentrated, or thrown in a solid beam something after the manner of a searchlight. It is easy to see in a general way how much light is coming through the reflector if of prismatic or opal glass and what the distribution of this light is.



Fig. 116. — Holophane "Extensive" Reflector.

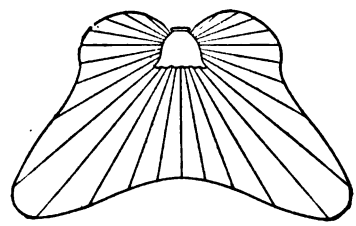


Fig. 117. — Character of Distribution.

In trying this experiment it will always be found that much depends on the exact position of the lamp in the reflector, as can readily be told by holding the reflector in one hand and the lamp in the other in thus exhibiting it, and then moving the lamp axially back and forth. In general, raising the lamp in its reflector tends to concentrate the light, lowering it tends to scatter the light. To take advantage of this fact, there are two distinct types of shade holders in ordinary commercial use, one of them holding the shade high and the other dropping it a little. If a particular distribution is desired, it can often be obtained merely by the use of one or another of these types.

The holophane prismatic reflectors are made in three general types corresponding to three general types of distribution, — wide, medium, and narrow angles respectively. Fig. 116 shows a recent type of the first named, intended for tungsten lamps, and Fig. 117 shows the character of its distribution curve, which tends to spread

the light rather widely. This so-called "extensive" reflector is of service where moderate lighting of a considerable area is undertaken with a few lamps. The exact form of the distribution curve varies somewhat with the arrangement of the filament and the position of the lamp in the reflector, but in a general way the maximum illumination is thrown at an angle of nearly 45 degrees downward, and the light in this direction is fully double the rated horizontal candle power of the lamp.

Fig. 118 shows the so-called "intensive" or medium-angle prismatic-glass reflector, and Fig. 119 its typical distribution. This form is a most generally useful reflector for ordinary cases of illumination. It covers, with considerable increase over the rated



Fig. 118. — Intensive or Medium Angle Prismatic Reflector.

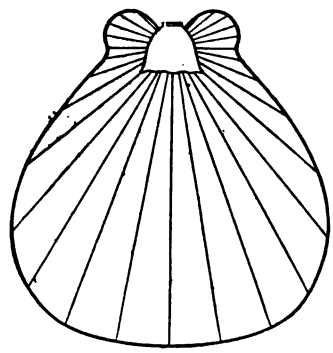


Fig. 119. — Typical Distribution of Intensive Reflector.

candle power of the lamp, an angle of from 60 to 90 degrees and in a general way gives through this angle 1.25 to 1.5 of the rated horizontal candle power. Reflectors having a medium angle of distribution should be used in the great majority of practical cases where fairly strong lighting is required with average heights of ceiling.

Now and then cases arise in which especially strong local lighting is required, or the lights have to be placed farther than usual from the working plane. In such instances the narrow-angle type of reflector is immensely useful. Fig. 120 shows the so-called focusing type of prismatic glass, and Fig. 121 its distribution. In this particular reflector the candle power in the axis of the beam and its immediate vicinity is about three to four times the rated horizontal candle power of the lamp. To meet the most

extreme conditions, prismatic-glass shades can be obtained which will give as high as six or seven times the rated horizontal candle power immediately in the axis. These of course are only fit for special uses, but sometimes are remarkably convenient.

With respect to these and all other forms of the holophane prismatic glass, it is not safe to assume that the distribution curve will rigorously follow the forms here shown except for the particular type of shade and the particular lamp with which it was tested. In case it is desirable to know the distribution curve accurately, it should be ascertained either from the makers or by trial for the particular combination of lamp and shade intended to



Fig. 120. — Focusing Type of Prismatic Gloss.

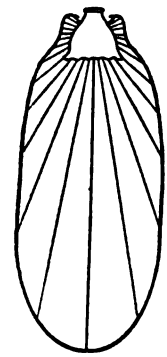


Fig. 121. — Character of Distribution Focusing Type Reflector.

be used. There are many varieties of these shades, so that almost any required curve can be hit by a little judicious selection.

Aside from the prismatic glass, there are many good types of bowl-shaped reflectors made of opal and similar glasses which diffuse a moderate amount of light and reflect the rest at fair efficiency from the interior surface. The best of these give a performance quite similar to that shown in Fig. 119, and they do good work in cases where medium-angle distribution is required. They do not, however, so effectively give either a wide-angle distribution or a very narrow-angle one. For obtaining a concentrated beam, some mirror reflectors and reflectors with a polished interior surface give results quite similar to those in Fig. 121. If the surface of these is made slightly matt and carefully shaped, a fairly concentrated beam can be obtained without the scattering reflections

from the filament which usually appear in a highly polished surface. Fig. 122 shows such a curve derived from an approximately parabolic steel reflector finished with aluminum on the inside and intended for use with a 25-watt tungsten lamp. It will be observed that the candle power in the axis rises to nearly five times the rating of the lamp. Reflectors of this description are of great service in workshop lighting, where lamps must often be suspended

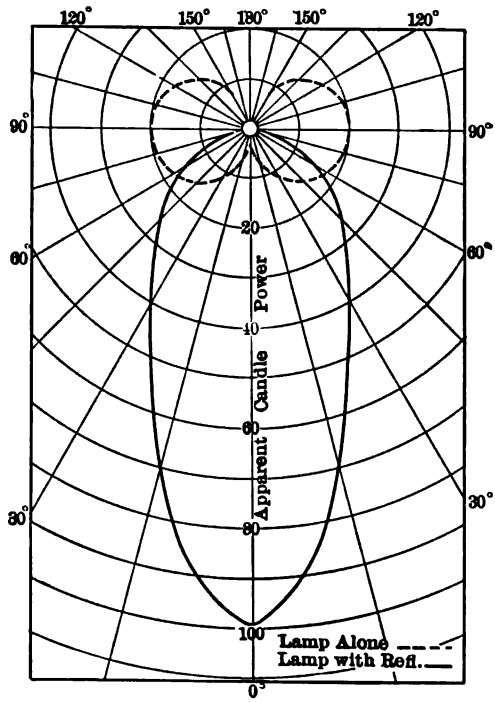


Fig. 122.

on drop cords and where the shades occasionally may get hard usage.

One cannot leave this subject of reflectors without mentioning an interesting and occasionally useful type in which, while the lamp is axially situated in the shade, the distribution of the light is unsymmetrical, so that if the shade be used on a bracket the light is thrown out from the wall instead of against it. This result is obtained in prismatic-glass reflectors by an ingenious combination of the original holophane structure with the totally reflecting

prisms already mentioned. Fig. 123 shows an asymmetric shade of this type, and Fig. 124 its very curious distribution of light. In Fig. 123 the left-hand half of the shade is of ordinary holophane construction, while the right-hand half is composed of totally reflecting prisms, with the result that more than two-thirds of the light is thrown to one side of the shade, as shown in Fig. 124. At 45 to 50 degrees below the horizontal on that side the available candle power rises to about one and a half times the rating of the lamp. Such asymmetric shades are manufactured in a number of forms, and it is unnecessary to state that to secure their proper operation great care must be taken to see that the portion containing the reflecting prisms is turned away from the direction which it is desired to illuminate. Somewhat similar effects can be obtained with opal glass or with metallic reflectors



Fig. 123.

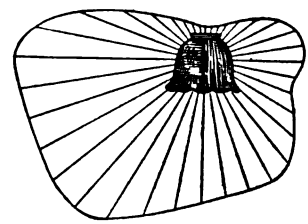


Fig. 124.

by cutting away a portion of one side of the shade and forming it accordingly, but these are open to the objection of exposing the lamp, which is generally undesirable.

The addition of a diffusing coating to a shade of any description somewhat tends to round the distribution curve, so that this treatment affects unfavorably very wide or very narrow angle reflectors, but is nevertheless occasionally desirable.

Finally, we must pass to a group of shades and reflectors of a highly specialized character, used for lighting walls and ceilings while concealing the source of light wholly or sometimes partially from direct view. These are employed either for lighting special things like pictures or bookshelves or for indirect general illumination wherein none or very little of the light which reaches the eye is derived from the radiant but chiefly from light diffused by walls or ceiling. Reflectors of the first class are practically troughs of section specialized for the work in hand. They are commonly

made of metal, usually employ lamps with their axes parallel to the length of the trough and well hidden by it, and may be lined for reflecting purposes either with mirror strips or with a brilliant interior coating of some description.

A very good example of such a device is shown in Fig. 125. This was designed for lighting bookcases in a library, is placed above and a little in front of the surface to be illuminated, and contains, preferably, tubular lamps in the position shown. The whole interior has a polished reflecting surface, and the direct rays of the lamp are cut off by the reflecting half-cylinder, in the axis of which it lies. The curve is specially designed to give uniform illumination over a considerable surface, and the group of tangents to the various points of the surface suggests at once the obvious way of laying out a reflector for such service. Indeed, the practical way of designing such reflectors is to start with the desired sheaf of rays necessary to illuminate the surface required and trace these back to an assumed position of the source, passing the reflector curve in the simplest possible way through the loci defined by the tangents derived from tracing back the rays. By following out this scheme, beautifully uniform illumination can be secured, particularly if the surface is slightly matt to avoid strong direct reflections of the filament. These reflecting troughs take a multitude of forms according to requirements, and are of considerable use in practical illumination.

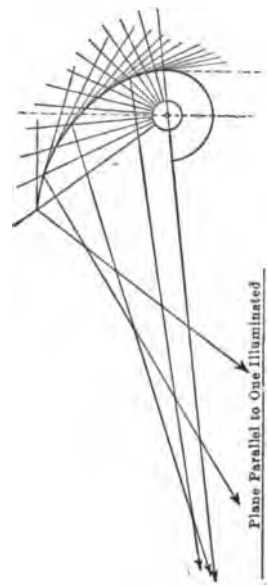


Fig. 125.

To a different category belong the devices intended deliberately for the indirect illumination of rooms. They belong in general to three types. The earliest of these is the reflecting cove, which is a curved cornice made structurally a part of the finish, and containing a recess in which can be placed lamps backed by a suitable reflector. The light from these lamps illuminates the curved plaster or painted surface of the cove above and contiguous portions of the ceiling into which the cove fades away. There is

therefore produced a brilliantly illuminated cornice which serves as the secondary source of radiation for the illumination of the

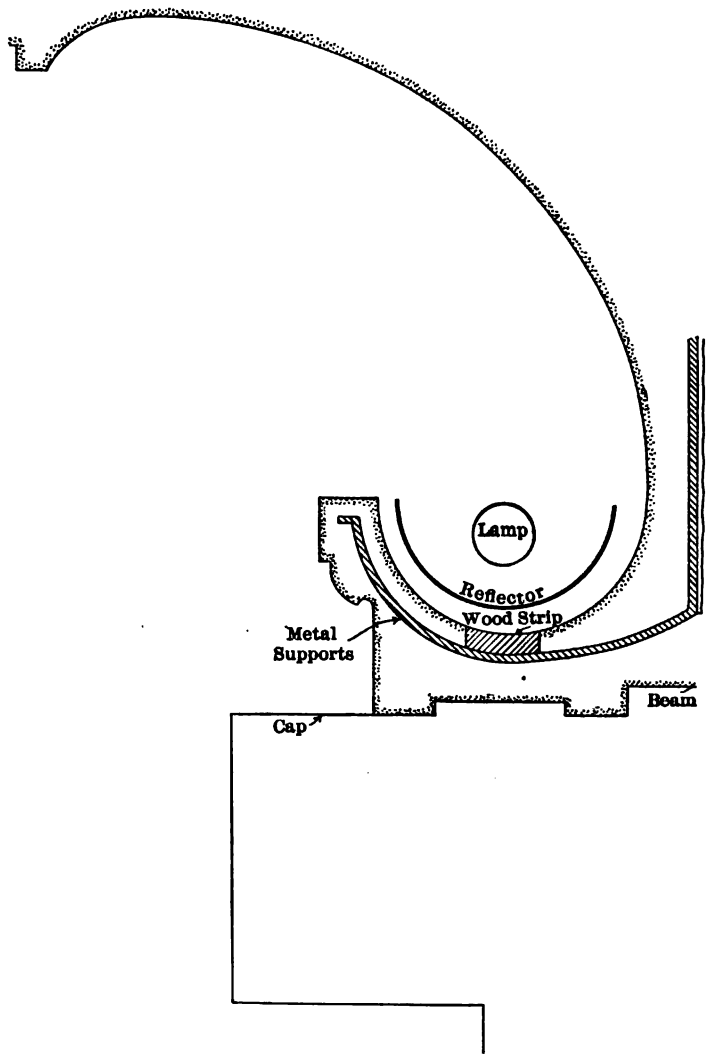


Fig. 126.

room. Such a cove has a cross section similar to that shown in Fig. 126. Its kinship to the curved reflector of Fig. 125 is obvious, but the object in the case of the cove is not to provide uniform

illumination over a wide area, but somewhat brilliant illumination over a comparatively restricted area, so that the curves are slightly different. The efficiency of this and other schemes for indirect lighting will be taken up in its appropriate place.

A second group of indirect-lighting fixtures are practically inverted reflectors throwing their light wholly or chiefly upon the ceiling, which then serves as a secondary source of light. Obviously, prismatic glass or metallic reflectors such as are used in the ordinary way can be readily applied to such indirect illumination,



Fig. 127.

the former providing more or less diffuse light, the latter concealing the source entirely.

The inverted arcs with metallic reflectors have been freely used for some years past in this way, but it is only with the advent of the metallic filament lamps that attention has been drawn to indirect illumination of this class with incandescent sources. One of the typical forms of indirect-lighting fixture for such use is shown in Fig. 127. This is a so-called "X-ray" reflector of corrugated glass silvered on the surface and then protected from tarnishing by a coat of elastic enamel. The reflector proper is carried

in a metallic casing with a suitable fixture provided for holding the lamp in the axis of the reflector, and the whole may be mounted on a fixture or suspended from chains so that the light which would otherwise fall below the horizontal is thrown entirely toward the ceiling. Of course it is necessary that the reflecting surface should be kept reasonably free from dust, in this as in all cases of reflectors for indirect lighting. The device, however, has come into considerable use as a convenient way of securing indirect illumination without special structural provisions in the building.

Finally, a group of fixtures should be mentioned which are especially designed to accomplish the same result that could be reached by using a prismatic glass reflector inverted; that is, they are so arranged as to throw a considerable part of the light upon the ceiling for indirect lighting and at the same time to diffuse a soft illumination through the space below. These direct-indirect or semi-indirect fixtures, as they are sometimes called, have great artistic possibilities and can be made to give beautiful illumination, but they have not yet come into large use, although the scheme is an old one.

All these methods of indirect and semidirect lighting are relatively inefficient, and not time enough has yet elapsed since the general introduction of high-efficiency incandescent lamps and mantles to develop the auxiliary appliances to their full measure of usefulness.

CHAPTER X.

DOMESTIC ILLUMINATION.

THE lighting of houses is a most interesting and generally neglected branch of illumination. Artificial light has been distinctly a luxury until within comparatively recent times, and in domestic lighting there has not been the same pressure of commercial necessity which has resulted in the general efforts to illuminate other buildings. Indeed, until within half a century there was very little effort at really good illumination in the home, everyone depending on portable lights, which could be brought directly to bear upon the work in hand; gas, which provides fixed radiant points, being confined to large cities, and in these to houses of the better class. Even at the present time very little pains is taken to arrange the lighting in a systematic and efficient manner.

The comparatively small areas to be lighted in dwellings, the small need for extremely intense light, and the very discontinuous character of the need for any light at all, render domestic lighting rather a problem by itself. Of ordinary illuminants all may be freely used for such work, save arc lamps and very powerful gas lamps, such as the large regenerative burners and the most powerful incandescent mantles.

Arcs are of very unnecessary power, hence most uneconomical, and are often so unsteady as to be most trying to the eyes. In the home, as a general thing, one does not keep the eyes fixed in any definite direction, as one would if working steadily by artificial light, so that far more than usual care must be taken to avoid intense and glaring lights. Therefore, arcs are highly objectionable, and the gas lights of high candle power equally so, particularly as the latter throw out a prodigious amount of heat and burn out the oxygen of the air rather rapidly.

As to other illuminants, the main point is to choose those of low intrinsic brilliancy, or to keep down the intrinsic brilliancy by adroit and thorough shading. Anything over two or three candle power per square inch it is well to avoid as needlessly

trying to the eyes without any compensating advantage save economy, which can better be secured in other ways.

Aside from the physiological side of the matter, very bright lights seldom give good artistic results or show an interior at anything like its true value. Of the common illuminants, gas and incandescent lamps are those generally most useful, while petroleum lamps and candles are even now auxiliaries by no means to be despised. Professor Elihu Thomson once very shrewdly remarked to the writer that if electric lights had been in use for centuries and the candle had been just invented, it would be hailed as one of the greatest blessings of the century, on the ground that it is absolutely self-contained, always ready for use, and perfectly mobile.

Now, gas and incandescents, while possessing many virtues, lack that of mobility. They are practically fixed where the builder or contractor found it most convenient to install them, for while tubes or wires can be led from the fixtures to any points desired, these straggling adjuncts are sometimes out of order, often in the way, and always unsightly. Besides, the outlets are often for structural reasons in inconvenient locations, and their positions need to be chosen very carefully if artistic effects are at all to be considered; so that while these lights are the ordinary basis of illumination wherever they are available, lamps and candles, which can be put where they are wanted and not necessarily where some irresponsible workman chose to locate them, are often most useful additions to our resources.

In domestic, as in other varieties of interior illumination, two courses are open to the designer. In the first place, he can plan to have the whole space to be lighted brought uniformly, or with some approximation to uniformity, above a certain brilliancy, more or less approximating the effect of a room receiving daylight through its windows. Or, throwing aside any purpose to simulate daylight in intensity or distribution, he can put artificial light simply where it is needed, merely furnishing such a groundwork of general illumination as will serve the ends of art and convenience.

While the first method is for purely utilitarian purposes often necessary, it is frequently uneconomical and inartistic in its results. Its sin against economy is in furnishing a great deal of light which is not really needed, while in so doing it usually

sends light in directions where it deadens shadows, blurs contrasts, and illuminates objects on all sides but the right one. The second method is the one uniformly to be chosen for domestic lighting, from every point of view.

In electric lighting the most strenuous efforts are constantly being made to improve the efficiency of the incandescent lamps by a few per cent, and an assured gain of even 10 per cent would be heralded by such a fanfare of advertising as has not been heard since the early days of the art. Yet in lighting generally, and domestic lighting in particular, a little skill and tact in using the lights we now have can effect an economy far greater than all the material improvements of the last twenty years. The fundamental rule of putting light where it is most useful, and concentrating it only where it is needed, is one too often forgotten or unknown. If borne in mind it not only reduces the cost of illumination, but improves its effect.

In applying this rule in practice, one of the first things which forces itself upon the attention is the fact that the conditions can seldom be met by the consistent use of lights of one uniform intensity, or one uniform characteristic as regards the distribution of the light around the radiant. Even one kind of illuminant is sometimes an embarrassing condition. Both the kind and quantity of the illumination must be adjusted to the actual requirements, if real efficiency is to be secured.

As has already been shown, the effective illumination depends upon two factors, — the actual power of the radiant in candles or other units, and the nature of the surroundings, which determine the character and amount of the diffuse reflection which reënforces the direct light. If the radiant in a closed space furnishes a certain quantity of light, L, then the strength of the illumination produced at any point within the space will depend, if the walls are nonreflecting, simply on the amount of light received from the radiant, in accordance with the law of inverse squares. If the walls reflect, then the total illumination at any point will be that received directly, L, and in addition a certain amount kL (where k is the coefficient of reflection), once reflected, a further amount k^2L twice reflected, and so forth. The total illuminative effect will then be:

$$L\,(1 + k + k^2 + k^3 + \ldots\ k^n).$$

As k is obviously always less than unity, this series is convergent

upon the limiting value $L\left(\frac{1}{1-k}\right)$, which expresses the relative effect of the walls in reënforcing the light directly received from the radiant.

It is clear from the values of k already given for various surfaces that such assistance may be of very great practical importance. A simple experiment showing the value of the light diffusely reflected is to read at some little distance from the radiant in a room having light walls, and then to cut off the direct rays by a screen close to the radiant and just large enough to shade the book. If the conditions are favorable, the amount of diffused illumination will be somewhat startling. A repetition of the experiment in a room with dark walls will exhibit the reverse condition in a most striking manner.

A good idea of the practical amount of help received from diffusion may be gained by computing the effect for various values of k. The following table shows the results for values of k between 0.05 and 0.95:

k	$L\left(\frac{1}{1-k}\right)$
0.95	20.00
.90	10.00
.85	6.66
.80	5.00
.75	4.00
.70	3.33
.65	2.85
.60	2.50
.55	2.22
.50	2.00
.45	1.81
.40	1.66
.35	1.53
.30	1.42
.25	1.33
.20	1.25
.15	1.17
.10	1.11
.05	1.05

In practice the interior finish of dwelling houses is highly heterogeneous, the walls being tinted and broken with doors and hangings, the ceiling being often of another color, and the floors covered with colored rugs or carpets, and generally provided with furniture at least as dark as the walls. The floor is in point of fact the least important surface from the standpoint of illumination, for it not

only carries the furniture, but from its position cannot diffuse light directly in any useful direction. So far as it is concerned, only the small terms in k^2 and higher powers enter the general equation, since the illumination diffused from below is not of much account.

These values show the great difference between good and poor diffusing surfaces in their practical effect. Reference to the table already given shows that ordinary wall surfaces give values of k ranging from about 0.60 down to 0.10 or less. These are likely to be reduced by the gradual absorption of dust at the surface, but it is quite within bounds to say that the effective illumination in a room may be nearly or quite doubled by the light diffused from the walls. If an average value of k is computed on the basis of the respective areas and values of k for the several surfaces of the room, the above table gives in practice a pretty accurate idea of the reënforcement of the direct illumination.

The ceiling is a very important consideration, for the light diffused downward is highly valuable. Vaulted ceilings are notorious in their bad effect upon the illumination. If used at all, they should be employed with full knowledge of the fact that they quite effectively nullify all attempts at brilliant general illumination, and when considerations of harmony permit, ceilings ought to be very lightly tinted.

As to the walls themselves, wainscoting and dark soft-finished papers absorb light very strongly, and render lighting difficult, while the white-painted wood and light papers freely used in Colonial houses produce exactly the reverse effect. The character of interior finish, being determined by the contemporaneous fashion, can of course seldom be really subordinated to the matter of illumination, which affects only personal comfort; but in planning a scheme of decoration it is necessary to bear in mind that the darker the general effect the more light should be provided

The outlets for gas and electricity provided for and quite adequate to light a brightly finished house, will prove entirely insufficient if a scheme of decoration in dark colors be afterward carried out, so that it is the part of wisdom to arrange the original outlets to meet the worst probable conditions for lighting. This will generally mean arranging for about double the minimum amount of illumination necessary on the hypothesis of strong diffusion from the walls.

If conditions demand or fashion dictates any attempt at very

bright illumination, a sort of simulated daylight, all matters relating to diffusion are of very serious import. Fortunately, such is not the usual case. Where the main purpose is that already strongly urged, — of merely furnishing such illumination as is necessary for practical or artistic purposes, — there need be no effort at uniform intensity of light or at making dark corners brilliant; and, while the aid of favorable diffusion is still important in reducing the total amount of artificial light furnished, it no longer so completely controls the situation.

With the data now at hand we can form a fairly definite idea of the quantity of light which must generally be provided. One can get at the approximate facts by considering the amount of

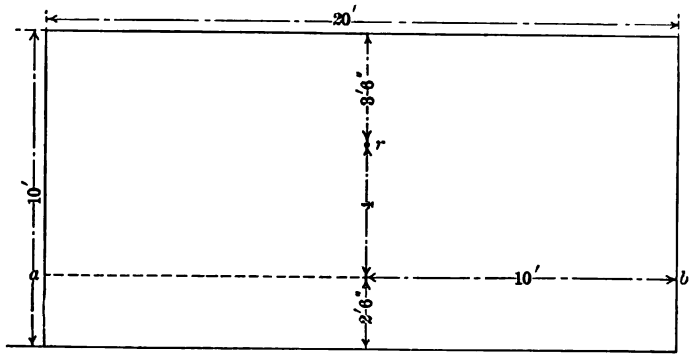


Fig. 128. — Vertical Section of Room.

light that must be furnished in a room of given size to bring the general illumination up to a certain value. The particular value assumed must depend upon the purpose for which the room is to be lighted. For instance, since 1 foot-candle is an amount which enables one to read fairly well, let us assume that we are to furnish, in a room 20 feet square and, say, 10 feet high, a minimum of 1 foot-candle.

To start with, we must make some assumption as to the amount gained by diffusion from ceiling and walls. For this, in a concrete case, we can make an educated guess from the data already given. In general, Wybauw found that in moderate-sized rooms the diffusion increased the effective value of the radiant 50 per cent, which, as it agrees pretty closely with our own values, taking into account a light ceiling, we will use for the present purpose.

Let the assumed radiant be at r, Fig. 128, and at a height of 6 feet 6 inches above the floor. Now draw an imaginary plane ab at a height of 2 feet 6 inches above the floor, and take this as the surface to be illuminated. If r is in the center of the room, the greatest distance from r to a corner of the plane ab will be $\sqrt{216}$ feet = 14.7 feet. Each candle power at r must be reduced proportionately, so that 1 candle at r would give $\frac{1}{216}$ foot-candle at the point in question. According to our hypothesis, diffusion aids by 50 per cent, so that instead of requiring 216 candle power to give 1 foot-candle in the remotest corner, the real amount would be 144 candle power, which would be handily furnished by a cluster of nine 16-c.p. incandescent lamps or their equivalent. The result would be a room quite brilliantly lighted, for, except

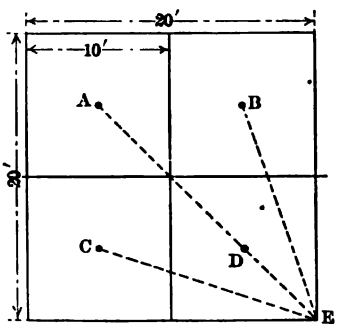


Fig. 129. — Floor Plan.

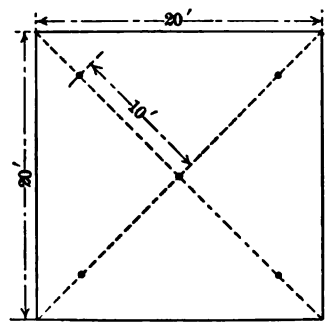


Fig. 130. — Floor Plan.

very near the walls, the illumination would be much in excess of 1 foot-candle, rising to 4 or 5 foot-candles upon the plane of lighting under and near the lights.

Such an arrangement of the lights is, however, uneconomical in the extreme, since the distant corners are illuminated at a very great disadvantage. Fig. 129 shows the advantage gained by a rearrangement. Here the room is divided by imaginary lines into four 10-foot squares, and in the center of each of these is a light 6 feet 6 inches above the floor, as before. Now, if a corner of the plane of lighting, as E, receives 1 foot-candle, the requirements are fulfilled. But E is distant from D just about 8 feet, from C and B almost exactly 16 feet, and from A less than 22 feet. It, therefore, receives, neglecting A, for each candle power at D $\frac{1}{64}$ foot-candle, and for each at C and B a total of $\frac{1}{128}$ foot-

candle, or, allowing for diffusion, $\frac{1}{13}$ and $\frac{1}{87}$ respectively (nearly), so that it at once becomes evident that four 32-c.p. lamps are more than sufficient to do the work.

Taking *A* into account, four 25-c.p. lamps would almost suffice, but obviously the maximum illumination is perceptibly lowered. It would be a maximum at the center, and for 32-c.p. lamps would there amount to 2 foot-candles. A still further subdivision would lead to still better distribution from the point of view of economy, and, indeed, something can still be gained by a further redistribution of the light; for, with lights arranged as in Fig. 130, at the center and on the circle inscribed in the room in question, five 20-c.p. lamps would very closely fulfill the conditions, reducing the total amount of light required to meet the assumed condition from 144 to 100 candle power in all.

Obviously, with a fixed minimum illumination and no other requirement, the conditions of economy will be most closely met by a nearly uniform distribution of the minimum intensity required. There is, however, a limit to practical subdivision in limited areas, such as rooms. In the case of large buildings, as we shall presently see, one can easily figure out the illumination on the basis just taken, but in domestic lighting we have to deal with a very limited number of radiants, at least in considering gas and electricity.

By far the best results are attained by providing a very moderate general illumination and then superposing upon it strong local illumination for special purposes. For example, in most rooms better practical results than those of Fig. 130 would be reached by following the same arrangement, but using four 16-c.p. or even four 8-c.p. lamps and one 32-c.p. lamp, the latter being placed near the point where the strongest illumination is required. The result would be to give the extreme corners all the light they really need, and to provide plenty of light where it is of most practical value. In ordinary domestic lighting the four smaller lights would often be put on brackets and the large one installed in a table lamp.

The same rules apply to the use of gas or other illuminants, always bearing in mind that the total amount of light required is strongly affected by the hue of the walls, and that the principal radiant should be placed where it will do the most good. Illumination thus regulated is both safer physiologically and far more

efficient in use of the material than any attempt at uniform distribution over the entire area.

One's choice of illuminants must obviously be governed by the question of availability. Incandescent electric lamps easily hold the first place when economy is not the first consideration, by reason of their being quite steady, giving out little heat, and in no way vitiating the atmosphere. They should *always*, however, be furnished with ground bulbs, or, better, so shaded as greatly to reduce their otherwise very high intrinsic brilliancy.

Next in order of desirability unquestionably comes gas. Used with the incandescent mantle burner, it is the cheapest known illuminant for domestic purposes unless electricity can be obtained at exceptionally low rates. Mantle burners should always be shaded, both to reduce the intrinsic brilliancy and to modify the hue of the light, unless some of the recent mantles giving an amber tone to the light are available. Ordinary gas jets, in case of need, give a good but expensive subordinate illumination.

Lamps and candles have strong merits for particular purposes, but are inferior for general work. The former are often used with good effect to furnish the principal radiant, which may be reënforced by small gas lights. Candles, on the other hand, are extremely useful for partial and subsidiary illumination, since they are the only available source of small intensity unless one goes to considerable trouble in wiring for tiny electric bulbs, which are better adapted to purely decorative purposes than to the regular work of illumination.

From this general basis of facts we can now take up the practical and concrete side of domestic lighting.

As to the distribution of the lights required for interior illumination, one must be guided by the intensity which is necessary. The examples already given show the general character of the problem. The laws upon which the solution depend may be formulated as follows: If we write L for the required or existing intensity of illumination in foot-candles at any point, C for the candle power of the radiant, and d for the distance in feet from that radiant, then:

$$L = \frac{C}{d^2} \qquad C = Ld^2 \qquad d = \sqrt{\frac{C}{L}}.$$

If the point in question receives light from more than one radiant,

the illuminative effects must be summed, and, if the radiants are equal,

$$L = C\left(\frac{1}{d^2} + \frac{1}{d_1^2} \cdots \frac{1}{d_n^2}\right)\left(\frac{1}{1-k}\right)$$

$$C = \frac{L}{\left(\frac{1}{d^2} + \frac{1}{d_1^2} + \cdots \frac{1}{d_n^2}\right)\left(\frac{1}{1-k}\right)}.$$

L is of course in foot-candles and C in candle power. In these expressions no account is taken of the varying angles of incidence of the light received from the several radiants. In principle, $L = \frac{C \cos i}{d^2}$, where i is the angle of incidence; in other words, the illumination decreases as it becomes oblique.

In certain cases account must be taken of this fact, but since, as a rule, objects to be lighted are oblique to the plane of illumination, and *cos i* is small only in case of rather distant lights, of which the entire effect is small, and since the diffused light cannot be reckoned with, having no determinate direction, the question of obliquity, particularly when the radiants are numerous and well distributed, has seldom to be dealt with. It is rendered the more uncertain by the notorious inequality of the distribution of the light from ordinary illuminants, and it must be remembered that the whole aspect of the matter is changed by the use of reflectors. It is better to take the obliquity factor by general average in assuming the illumination required.

In ordinary interior illumination one constantly meets limitations imposed by structural or artistic considerations. For example, we have already seen that the arrangement shown in Fig. 130 was highly desirable for economic reasons. The five lamps dangling by cords or rods, from the ceiling of a room 20 feet square, might be tolerated in an office, but would be quite inadmissible in a drawing room. For domestic lighting one is more likely to use chandeliers, side brackets, and ceiling lights. The last-named have been considerably used of late, sometimes with beautiful effects, sometimes unwisely.

To examine the effect of ceiling lights on the situation, refer to Fig. 131, which shows the same room as Fig. 128. Assuming the same general conditions, let us find the illumination at a point p in the plane of illumination when given by a light r in the old

position, and a ceiling light r', 6 inches below the ceiling. The light being assumed as of 16 candle power, the light at p is $L = \frac{16}{41} = 0.39$ foot-candle, when the lamp is at r, or $L = \frac{16}{74} = 0.21$ when the lamp is at r', close to the ceiling, neglecting diffused light.

In a room very bright with white paint or paper, having, for example, $k = 0.60$ and $\left(\frac{1}{1-k}\right) = 2.50$, the total illumination would be $0.39 + 0.97 = 1.36$, and since the diffusion does not materially change with the position of the light, the illumination in the second case would be, roughly, $0.21 + 0.97 = 1.18$; in other words, the

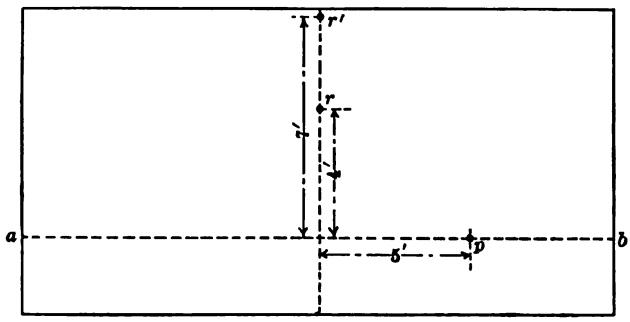


Fig. 131. — Location of Ceiling Lights.

change in position of the light would make but a small change in the intensity of the illumination.

There is evidently some error made in assuming that diffusion increases the illumination by a certain *ratio*, and Wybauw's hypothesis of replacing the diffused light by an imaginary radiant directly above the real radiant involves the same error. It is probably nearer the truth to assume, in case of an apartment having several radiants, that the total illumination at any point is that due to the lights severally, plus a uniform illumination, due to diffusion and proportional to k and C.

The practical upshot of the matter, however one may theorize on the rather hazy data, is that shifting the lights in a room from their usual height to the ceiling does not affect the illumination seriously if the walls and ceiling diffuse strongly, while if they are dark the change is decidedly unfavorable. This does not, however,

imply that ceiling lights should not be used in dark-finished rooms, although it is very plain that if they are so used the lamps should be provided with reflectors, or themselves form reflectors, as in some lamps recently introduced.

If the walls have a very low coefficient of diffusion it is obvious that all light falling upon them is nearly wasted, at least from the standpoint of illumination, and therefore the economic procedure is to deflect this light so that instead of falling upon the walls it shall be directed upon the plane of illumination, which is chosen to represent the average height from the floor at which are the things to be illuminated. If reflectors or their equivalents are skillfully applied, the radiants, for the purpose in hand, are nearly or quite doubled in intensity, so that there is a good opportunity for efficient lighting. But these reflecting media must be used with caution to avoid the appearance of beams giving definite bright areas, and by far the best results may be obtained by using diffusing shades in every such case. So far as economy of light is concerned, reflectors can be advantageously used wherever the effective reflection exceeds the total diffusion coefficient of the walls. For example, with a hemispherical reflector having a coefficient of reflection of 0.70, the hemispherical intensity of the radiant is 1.70 C, assuming a spherical distribution of the light. This value corresponds, so far as the plane of illumination is concerned, with a diffusion of $k = 0.40$, which signifies that, except in very light finished rooms, the radiant is used more efficiently by employing a reflector than by trusting to the really very serviceable diffusion from the walls.

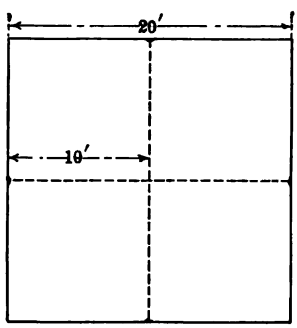


Fig. 132. — Side Lights.

The use of side lights close to the wall, or on short brackets, is preferable to lighting from the ceiling in certain cases, as when strong local illumination is needed. Reflector lamps may here again be used with very great effect if the walls are at all dark in tone. Fig. 132 gives in diagram the simplest arrangement of such lamps. We may assume their height as a trifle less than in the case of the suspended lights, say, 3 feet above the plane of illumination, and that they are equipped with reflectors giving a hemispherical distribution of

light. In Fig. 132 the positions of the lamps are indicated by black dots, as before. It is evident that the corners will be the points of minimum illumination, and that in the central part of the room the lighting will be rather weak, although, on the whole, the distribution of light will be good. With help from diffusion to the extent assumed in the last example, four 20-c.p. lamps would do the work, while with dark walls the case would call for at least four 32-c.p. lamps. In fact with dark walls lighting from brackets becomes extremely inefficient.

Now, summarizing our tentative arrangements of light, it appears that to illuminate a room 20 feet square and 10 feet high on the basis of an approximate minimum of 1 foot-candle will require from 80 to 144 effective candle power, according to the arrangement of the lights, if the finish is light, and half as much again, at least, if the finish is dark. The floor space being 400 square feet, it appears that the illumination is on the basis of about 3 to 5 square feet per effective candle power. The former figure will give good illumination under all ordinary conditions; the latter demands a combination of light finish and very skillfully arranged lights.

For very brilliant effects, no more than 2 square feet per candle should be allowed, while if economy is an object, 1 candle power to 4 square feet will furnish a very good groundwork of illumination, to be strengthened locally by a drop-light or reading lamp. The intensity thus deduced we may compare to advantage with the results obtained by various investigators, reducing them all to such terms as will apply to the assumed room which we have had under discussion.

Just deduced	1 c.p. per 3 sq. ft.
Uppenborn	1 c.p. per 3.6 sq. ft.
Piazzoli	1 c.p. per 3.5 sq. ft.
Fontaine	1 c.p. per 7.0 sq. ft. (approximation).

In very high rooms the illumination just indicated must be somewhat increased, owing to the usual necessity for placing the lamps rather higher than in the case just given, and on account of the lessened aid received from diffuse reflection. The amount of this increase is rather uncertain, but in very high rooms it would be wise to allow certainly 1 candle power for every 2 square feet, and sometimes, as in ballrooms and other special cases requiring the most brilliant lighting, as much as 1 candle power per square foot.

On the other hand, in most domestic lighting, the amount of lighting needed may be reduced by a little tact. Ordinary living rooms, such as parlors, libraries, and the like, do not require to be uniformly and brightly lighted in most cases. It is quite sufficient if there is ample light throughout the main portion of the room.

A groundwork illumination of 0.5 foot-candle over the whole room, plus a working illumination of 1.5 to 2 foot-candles in addition over a part of the room, gives an excellent result. This is something the result that would be reached in Fig. 130 by using a 32-c.p. central lamp and four 10-c.p. lamps for the rest of the room. Dining rooms need ample light upon the table, but do not in the least require illumination of equal power in the remote corners. Sleeping and dressing rooms do not require strong light so much as well-placed light. A bedroom of the dimensions we have been discussing could be very effectively lighted with three or four 16-c.p. lamps, provided they were placed where they would do the most good.

To go into detail a little, perhaps the most important rule for domestic lighting is never to use, indoors, an incandescent or other brilliant light, *unshaded*. Ground or frosted bulbs are of much service when incandescents are used, and opal shades, or holophane globes, which still better reduce the intrinsic brilliancy, are available with almost any kind of radiant. Ornamental shades of tinted glass or of fabrics are exceedingly useful now and then, when arranged to harmonize with their surroundings.

In incandescent lighting the lamps may be placed in any position. With gas or other flame radiants ceiling lights are not practicable, although inverted Welsbachs may be raised fairly near the ceiling. As to the intensity of the individual radiants, considerable latitude may be given. In many instances, incandescents or gas or other lights of as low as 8 to 10 candle power are convenient, while for stronger illumination radiants of 15 to 20 candle power reduce the cost of installation, and for special purposes lights of 30 to 50 candle power, incandescents or incandescent gas lamps, are most useful.

At the present time the general introduction of the tungsten lamp and of the small mantle burner has made the task of efficient domestic lighting very much easier than ever before. At the price customarily charged for current in house lighting, using carbon

filament lamps is simply a waste of money without any conceivable benefit by way of excuse.

The only difficulty with the tungsten lamp is its fragility, which is still a serious matter in spite of reputed and real improvements. The danger of accidental breakage from blows or jarring is the one source of annoyance in using these lamps in house lighting. Barring accident, their life is sufficiently long to make it well worth while to use them even at the present high price, but since in house lighting there is very seldom any necessity for using the larger sizes of tungsten lamps, the fragility of the slender filaments found in the smaller sizes must be taken into serious consideration. It is very rarely that one wishes to use a lamp larger than 40 watts in domestic lighting. Most of the work falls to the 25-watt size, and a very considerable proportion of lamps for house lighting will be of still smaller size, — 15 watts or thereabouts, when these lamps are available, as they even now are at reduced voltage.

These small tungsten lamps should be generally either operated by wall switches or provided with pendent switches or pull switches. Key sockets should be employed with caution for the tungsten lamps of 25 watts and below, not so much on account of the danger from the snap of the switch as for the risk of fumbling around the socket and accidentally hitting the fixture hard enough to break the lamp. The writer, however, uses a good many 15-watt 55-volt tungsten lamps in his own house on key sockets with very little trouble from breakage, but these low-voltage lamps are somewhat sturdier than usual, and it is questionable whether the same immunity from trouble would have been experienced in using 110-volt lamps of this small size. There is no reason why a large proportion of lamps in a house should not be upon switches. It will here be well to take up systematically the lighting of a house, considering carefully both the amount of light required and the way in which it is advisable to apply it.

The lighting of a house has a very intimate relation to the decorative effect sought. Indeed, all the difficulties of the situation are due to the concessions which have been made to the decorative situation. Unfortunately there are no fixed canons of taste regarding interior decoration. It is, on the contrary, almost purely a matter of fashion, without the slightest philosophic basis; consequently, interiors which would have been considered charming fifty years ago may be decried as execrable at the present

time, and again lauded as the ideal of decorative art fifty years hence. At least such is the history of the subject in the past, which there is every reason to expect will be repeated. In planning the illumination of a house, therefore, one must be prepared to meet occasionally conditions that render effective lighting well-nigh impossible, as well as others in which it becomes extremely easy.

The first task of the illuminating engineer is to provide a sufficient number and capacity of outlets to give good illumination in spite of all the subsequent efforts of the decorator. These outlets need not be used to their full capacity, but they should be available in case of necessity. The four usual methods of lighting a room are as follows: ceiling lights, pendent lights, either in chandeliers or on flexible cords, brackets, and table lamps. The choice between one of these devices and another is determined by the character of the room to be illuminated. Just at the present moment decorators, who are an imitative folk, are booming the bracket. Now, the bracket in small or exceptionally narrow rooms of light finish can give excellent results in illumination, but if the wall finish is dark the effectiveness of the lamp placed near it suffers greatly, and it is not an easy matter to throw light out into the room from a bracket without the use of shades or reflectors of very special design. Moreover, there is a constant temptation, from a slavish following of old precedents, to make a bracket simulate a sconce, or at least so to design it as to require its equipment with candle lamps. From the standpoint of the illuminating engineer the candle lamp is something to be avoided, not only on account of the obvious objection that it is at best a shabby counterfeit of a candle, but from the fact that candle lamps are highly special as an article of manufacture, inefficient, and difficult to shade adequately without cutting off an objectionably large proportion of the light.

Some of the most unsuccessful and inartistic lighting which the writer has ever had the misfortune to see has been by the misapplication of brackets as the only source of light to rooms with extremely dark wall finish. The use of brackets in this way is historically inharmonious, since the scheme belongs to a period of civilization in which either very little light was required, — far less than can suit even the most modest modern requirements, — or when the brackets were used as auxiliaries to chandeliers, which

furnished the major part of the lighting. This combination of chandelier with a multitude of glittering candles, and candles used as side lights to reënforce it, is capable of giving altogether charming results; but the side brackets alone, fitted with imitation candles, are both ineffective and out of keeping with the situation in which they are generally found. If one wants sconces or the like as bric-a-brac, he should at least have the courage of his convictions and fit them with genuine candles.

Chandeliers can be made both beautiful in themselves and effective, but they belong properly in large and stately rooms, high enough to give them place without breaking up the continuity of the room, and big enough to allow a chandelier on a sufficient scale to give it its historic decorative character. Like the bracket, it belongs to special rather than to general conditions. Lamps placed close to the ceiling either singly or in clusters form essentially a modern type of lighting fixtures, since they could not have been used successfully prior to the introduction of electric lights. They are, therefore, too frequently held in horror by the decorator, although in the hands of some of the skillful fixture designers at the present time very graceful and harmonious examples have been turned out. For domestic use they are extremely useful in small- and moderate-sized rooms, and there is assuredly no logical reason why a fixture, in itself well designed to meet the conditions imposed by modern illuminants, should not be artistically every bit as good as any possible adaptation of such illuminants to fixtures which belong characteristically to a different period and to methods of illumination now obsolete. A fixture is not necessarily good merely because it is a somewhat slavish imitation of a seventeenth- or eighteenth-century model.

Reading lamps of one kind or another have a history as ancient as could be desired. They are, moreover, available in many forms, suitable to almost every possible requirement, and should occupy in modern domestic lighting a considerably more prominent place than is generally accorded to them. Their installation requires a liberal supply of wall or baseboard plugs and floor receptacles if they are to be successfully adapted to electric lighting. There is no reason why similar taps should not be applied to gas lighting, although the usual form of the gas reading lamp is dependent for its supply on piping from a gas chandelier.

A combination of table lamps with brackets or any other com-

mon means of lighting can be made effective from every point of view. Sometimes, though rarely, the lighting can be trusted to lamps alone. The writer, for example, found it desirable to illuminate his own library in this way, the room being long and low, so that its continuity would have been hopelessly broken by ceiling lights or chandeliers, and lined with bookcases to an extent that precluded the effective use of brackets. The use of lamps on this scale is not particularly economical, owing to the character of the shades which generally have to be used, but otherwise it leaves little to be desired.

Finally, one may mention various plans for indirect lighting, such as have already been described. The design of artistic fixtures for this class of work has not progressed far enough to warrant one in being enthusiastic about it, and the concealed cornice lighting, while it may be made very effective, is objectionable in the house on account of extreme difficulty in keeping the reflecting surfaces clean. It therefore is a form of illumination which should be used with caution.

A word here concerning the matter of fixtures, whatever type of illumination be attempted. The fact must be recognized that fixtures may have a high decorative value if properly designed. With this phase of the matter the illuminating engineer is not directly concerned, except in so far as bad design may interfere with the suitability of the fixtures for the purpose of their use, which is to supply light. The best fixture designers fully recognize this, and can, if given a free hand, produce fixtures which are excellent from every point of view. From the standpoint of illumination, the chief thing to be borne in mind is that the fixture must not be so located or so formed as seriously to interfere with its illuminating function. The writer has in mind one case in which some very elaborate wrought-iron chandeliers were provided with deep bell-shaped black iron receptacles within which the incandescent lamps were located and almost wholly concealed. After divers ineffective efforts to secure a perceptible amount of light from these, the unfortunate owner resorted to "gas arcs" of the most glaring and undecorative description.

The most effective way of protecting a client against bad fixtures is to persuade him to cut down his fixture appropriation to a point that will enforce simplicity and unobtrusiveness. The worst fixtures, as a rule, are the somewhat showy ones of

medium price in which an attempt has been made to obtain a so-called decorative effect without the skill in design, and finish in execution, really necessary for good results.

If one wishes to make fixtures a distinct decorative feature in an interior, he must be prepared to pay for the privilege, and so far as illumination is concerned its employment for a purely decorative object is quite legitimate. When so used the man who pays the bills should clearly understand that he is using light as a decorative element, quite irrespective of its primary use for illumination, and must also understand that he is decorating rather than illuminating his room by such use of lights. If he is willing to pay for it on this basis, that is his business, and no concern of the illuminating engineer.

The writer recalls a case in his own practice where a private library was subjected to an electric light bill about ten dollars a month in excess of what should have been required under ordinary illuminating practice, merely on account of the nature of the interior finish and the wholesale use of brackets with candle lamps. The owner grumbled at his electric light bills, although he probably received florists' bills of much larger amount, also incurred for decorative purposes, with entire equanimity.

Some attention has here been paid to this phase of the matter because the illuminating engineer and decorator are popularly supposed to be at swords' points. Such is not at all the case in reality, since the illuminating engineer is not concerned with the taste of his client in the selection of fixtures or bric-a-brac. He should, however, make it plain that if he has to work under certain fixed limitations regarding decorative effect, he cannot be expected to give good illumination for the purpose of seeing without correspondingly large cost to the owner. And, on the other hand, there should be no concealment of the fact that the decorator may be advising the use of finish and fixtures that will double or even quadruple the cost of lighting a room for the ordinary purpose of its use.

Taking up now the lighting of a house in detail, one may summarize the situation about as follows:

A. Halls. — The illumination of these depends entirely on the way in which they are to be used. Ordinary entrance halls can generally be sufficiently lighted on the basis of 4 or 5 square feet per rated candle power. Elaborate halls, which are likely to be

used considerably in entertaining, as part of the working space, should have a larger allowance of light, say 1 candle power to every 2 or 3 square feet. The basis of reckoning is here nearly independent of the height of the ceiling for the reason that dwelling houses do not commonly present any extremes of height requiring special consideration. Back halls and other subsidiary halls require less light, perhaps 1 candle power to 6 or 7 square feet, since they are used only as passageways. Lanterns and side brackets are the usual means selected, and the location should be such as to thoroughly light the stairway. With exceptionally low ceilings, lanterns are out of scale unless small and located close to the ceiling, and brackets will more generally answer the purpose. Occasionally one sees very beautiful staircase lighting from a newel post, but the scheme is one that had better be avoided except in work on a large scale and when the designer can be given *carte blanche* for the necessary fixture.

B. Reception Rooms. — These are usually of somewhat formal character, to which the fixtures must correspond. The amount of light required at times is considerable and should be provided on the basis of not more than 3 square feet per candle power, preferably 2, although the subdivision of units should be such as to allow half or one-third of the light only to be used under ordinary conditions. One generally finds it advisable in reception rooms to use brackets or chandeliers, or frequently a combination of the two, the chandelier being really suitable only in rather large and high rooms, and better replaced for low ceilings by a ceiling fixture. Sometimes side brackets and table lamps make a suitable combination, the former for general illumination, the latter for added brilliancy when needed. Here, as everywhere in a house, it should be the invariable rule of the illuminating engineer never to allow a bare incandescent lamp to be visible from any point where one is likely to be placed. If bare lamps are to be used at all, they should be behind diffusing shades of one sort or another, otherwise the lamp should be completely frosted, and even the use of frosted lamps should be shunned on account of their generally too high surface brilliancy.

C. Music Rooms. — Music rooms are employed, or are supposed to be employed, for a definite function. They do not ordinarily require high illumination save near the instrument, which is best cared for by a suitable lamp so as to throw the light upon

it and not into the faces of the audience. Above all things, the lighting should be restful in effect and the lights extremely well shielded. Unobtrusive chandeliers or ceiling clusters with lights well screened are the best means of meeting this requirement.

Brackets are particularly objectionable in such rooms, inasmuch as they are constantly in the field of view and it is rather difficult to screen the lights adequately. The amount of light provided should be on the basis of 3 to 4 square feet per candle power, the latter figure being quite all that is necessary, unless the room is to be at times used for general purposes requiring a little more illumination. These figures presume a wall finish not excessively dark, and any room wainscoted in dark wood, or finished in paper or paint in dull reds, greens, browns, and blues, would require not less than 50 per cent more light than here specified. Now and then some form of concealed lighting is effectively used in a music room. The main point, however, is that in any room where an audience is to be assembled the light must be kept out of their eyes, since they are not at liberty to change their positions and escape it.

D. Libraries. — By tradition libraries are usually given a dark finish, and if actually used as libraries the walls are lined with bookcases to an extent which implies powerful absorption of light. Further, they are supposed to be used for reading, which requires fairly good illumination, so that the amount of light supplied must of necessity be considerable. The best way of furnishing it is to apply a groundwork illumination, either from fixtures near the ceiling or from brackets, in either case thoroughly shaded, and then to strengthen it locally by well-shaded reading lamps.

The total amount of light required will be commonly 1 candle power for 3 or 4 square feet, about half the total amount being put in the general illumination and half in the reading lamps. In case of exceptionally dark finish a total of 1 candle power to as low as 2 square feet may be desirable. Lamps near the ceiling are much to be preferred to brackets for general illumination in a library, since with these latter it is almost impossible adequately to light the bookcases, which must lie nearly in the same plane with the brackets. Further, if a library is really used, it is usually very difficult to find any space for wall brackets without interfering with the bookcase space. The library should be wired

for an ample supply of current, floor plugs and baseboard plugs being especially useful.

As a rule fixtures, here as elsewhere, should have the lamps pointing either directly up or directly down, preferably the latter. Fixtures having a lamp at an angle are not in the least necessary for artistic results, and are extremely objectionable from the fact that lamps so placed are exceptionally difficult to screen properly. One is practically obliged in using such fixtures to employ globes completely inclosing them, which waste an unnecessary amount of light without gaining important advantages. In ceiling lights either inclosing globes or reflecting shades can be employed, which can be made adequate to cover the lamp, and can be given directive action sufficient to supply good illumination beneath.

E. Living Rooms. — A living room, used as such, is best lighted by a combination of table lamps and general illumination from lights placed at or very near the ceiling. The amount required is a trifle less than in the ordinary library on account of the usually lighter finish. One candle power to 4 square feet, at least half of it being in table lamps placed where they will do the most good, ought to be adequate. Few living rooms are large enough or formal enough in character to make the use of chandeliers desirable. Nothing is more garish and generally ineffective than the ordinary three- or four-armed chandelier with the lights at an angle and placed at a height where they are likely to be hit by unguarded motions or the passage of someone more than usually tall. Moreover, lights in such a place cannot be properly screened except by closed globes, and even these are thrust into the face of anybody entering the room. If the lights are placed high, at or near the ceiling, they are out of the ordinary field of view and can be made to put illumination where it will be useful.

F. Dining Rooms. — The dining room, more perhaps than any other room in the ordinary house, is the prey of unthinking and irresponsible fashion. Table lamps, except when small and for purely decorative functions, are bad, since they obstruct the view across the table. Now and then in dining rooms of the formal and stately type chandeliers may be used with very beautiful effect, but they belong distinctively to very high rooms giving ample space for decorative effects, carried well above the immediate view of the persons in the room.

Side brackets, unless for decorative use only and with the lights

exceedingly well screened, are highly objectionable here, since they must be shining directly into someone's face and cannot be escaped. With a room too low and too formal to permit a proper chandelier, ceiling clusters answer admirably, and from the standpoint of comfort a good deal is to be said for the domes, which at times have been popular and may be highly decorative, although at present anathema from the ephemeral standpoint of fashion.

There is much to be said, too, for concealed and "semi-direct" lighting in rooms of this sort, where it is highly undesirable to have a glare of light in the faces of those sitting at table. The amount of light required is fortunately not great. One candle power to 4 or 5 square feet is ample if applied with any intelligence.

In passing, the writer may say that altogether the most beautiful effect he has ever seen in any private dining room was produced by the use of an exquisite eighteenth-century chandelier in crystal, reënforced by candelabra, all carrying real candles, without any aid from modern illuminants.

G. Kitchen and Pantries. — The service portion of a house in general requires about the same illumination found elsewhere, with this exception, that in some of the rooms already mentioned provision must be made for exceptionally bright lighting on particular occasions. The service portion requires merely good working illumination at all times. By far the best way of securing this is by lights placed practically at the ceiling with suitable prismatic glass or similar reflectors. In rooms of ordinary height this is the position of the greatest advantage. Lights in a kitchen may be located at one or more points as the arrangement of the working space requires.

The total amount of illumination required is not great. In the kitchen itself an average of 1 candle power to 5 or 6 square feet is ample. Pantries require a little more, being generally active working spaces. One light, which sometimes has to be on a bracket, although a properly located ceiling light frequently answers, should be arranged to give good light in the interior of the ice chest. All lights in the service portion should be on wall switches or pull sockets, if tungsten lamps are to be used, as is commonly desirable. In lighting the service portion of a house with gas, the same provisions for amount of light and general location hold, and it pays to use automatic gas lighters, which pay for themselves many times over in decreased breakage of mantles. The same is true

of the use of gas lights through all other portions of the house, the rules for amount of light and most advantageous location holding rigorously true, irrespective of the particular illuminant used.

The chief trouble with gas lighting is the supposed necessity of getting the lights far enough down to enable them to be lighted with a match and the consequent wholesale use of inartistic and inconvenient fixtures of the chandelier type. In these days of inverted mantle burners and thoroughly-worked-out systems of lighting them, there is no difficulty in getting adequate and convenient illumination from gas. The combination gas-and-electric fixtures are generally abominations from the artistic standpoint, quite unnecessary, and not to be recommended for any purpose.

H. Bedrooms. — Bedrooms generally suffer rather from badly placed lighting than from inadequate amount. The actual amount required is not large, say 1 candle power for every 5 square feet in rooms of ordinary finish. These are the only rooms in the ordinary house in which brackets are positively advantageous, although here they generally could be reënforced to advantage, at least in electrically lighted houses, by a small ceiling light for purposes of general illumination.

Bureaus and dressing tables can be better lighted from swinging-arm brackets than by any other device yet tried, since these brackets can be moved to exactly the position where they will be of the most service. The one place where a light should never be placed is above and a little in front of the bureau or dressing table. This is the position often picked out by the thoughtless and ignorant, who act as if the mirror and the top of the bureau were the things to be lighted, instead of the person standing or sitting in front of them.

A swinging bracket, placed not too high and carrying a lamp of moderate candle power well shaded, is the form of local lighting best suited for such use. An additional light placed over or beside the bed and easily reached from it is a most useful addition to the bedroom lighting equipment. At least one light should be switched from the door, and the others may either be switched at the lamps or from a point near at hand. Three lighting units are commonly required for the ordinary bed room, more if the room is exceptionally large. These units should preferably all be small, unless a special lamp be desired for reading purposes. The same general conditions hold for lighting with gas. Sometimes a night

lamp is a desirable addition; with electric lighting, a 2-c.p. lamp is excellent for this purpose; with gas lighting, one small jet shielded against the danger of being blown out by draughts.

I. Billiard Rooms. — Where these are found in private houses they are generally small, containing only one table. This requires very strong lighting, say two lamps with downward, somewhat concentrating reflectors, each lamp from 30 to 50 candle power and equally spaced over the table area. For electric lighting two 40-watt or 60-watt tungstens are generally sufficient. With gas lighting two small inverted Welsbachs give similar candle power. These lights should be placed rather high, so as to be as far as possible out of the way of the cue in massé shots. There is a good deal to be said for the use of indirect lighting in billiard rooms for the avoidance of shadows, which, while mostly suppressed by the dark hue of the cloth, are sometimes embarrassing. In case this method is tried, two 100-watt tungstens or two large Welsbachs, with suitable reflectors to throw the light on the white ceiling, are none too great an allowance of light for the work. When the lighting is direct, care should be exercised in picking out the reflectors so as to avoid streaks of light from direct reflections of the filament. A matt interior surface with ordinary reflectors, or satin-finished prismatic glass, would generally meet this requirement.

J. Basements. — Rooms in the basement of a house commonly require only a very moderate degree of lighting, varying from 1 candle power to 4 square feet in the portions most used to half this amount elsewhere. The location of the lights is generally definitely fixed by the shape of the subdivisions in the basement or cellar. Lights generally should be placed as near the ceiling as possible.

K. Bathrooms. — Very little need be said for these. One small light is usually sufficient and is best placed on a swinging bracket. The bathrooms are usually of such size that the smallest ordinary unit gives ample illumination, especially since the finish as a rule is very light.

L. Closets. — Most closets unless extremely well lighted from the room require one small light, generally at the ceiling. The same is true of storerooms and attic space. It is sometimes good policy to place these lights, and particularly those in closets, on automatic door switches, so that they will not be left burning through carelessness. If only used in one or two places it is com-

monly unnecessary, but where a considerable number of closets are thus fitted it is wise to use automatic switches.

In general, domestic lighting is peculiar, in that a very large number of lamps relatively to the average or maximum load is installed. The ordinary dwelling house of ten rooms or above will require from forty lights upwards, and the number of outlets, including base plugs, is likely to be half as great again unless rigorous economy in the original installation is necessary. The economy of domestic lighting depends on the convenient arrangement of the lights in such wise that only those necessary at any time shall be in use; hence it saves money to install ample and convenient switching, or, in case of gas lighting, automatic lighting apparatus.

Electric lights in the halls, both front and back, and in the cellar, should be put on three-way switches, so that they can be lighted and extinguished from more than one place. Clusters and chandeliers when used may advantageously be wired in two or more circuits, so that except when full illumination is needed a small amount of light can be used. In an ordinary electrically lighted house at least nine-tenths of the illuminating work can best be done by 25-watt and even 15-watt tungstens, very few larger lamps or special lamps being ordinarily required. It is advisable, too, in providing the wiring, to have several taps of ample capacity, in addition to the lighting connections, provided for small heating devices, fan motors, and vacuum-cleaner connections. Occasionally someone objects to the relatively white light of tungsten lamps in domestic use, but this can so easily be toned down by the use of tinted shades or faint tinting of the lamps themselves by dipping, that it constitutes no serious objection; and the efficiency, even after the color is modified, lies always with the metallic filament lamp.

CHAPTER XI.

LIGHTING LARGE INTERIORS.

BEFORE passing to the interesting problem of lighting large interiors, it may be well to consider the group of transitional cases represented by the rooms of an ordinary office building, and particularly the smaller ones. Such buildings are variously arranged, presenting rooms of divers sizes, used for offices or small counting rooms, and occasionally for the display of goods. As a rule they are of moderate size, ranging from 200 to 1000 square feet, and commonly run from 11 to 13 feet in height of ceiling. The ordinary finish is on the whole thoroughly light, although the wood-work may be dark, and in many instances the natural light is rather poor, so that artificial lighting has to be resorted to for a considerable part of the day. The outlets in office buildings are generally badly planned, the only redeeming feature being ceiling outlets, useful for general illumination. Brackets, when found, are generally fixed with the lights pointing downward at an angle of 45 degrees, by all means the worst possible position, and are chiefly useful as attachment places for portable lamps. Suitable baseboard outlets for adjustable plugs are too often infrequent and inconveniently placed.

Now, in all such rooms there are two radically distinct modes of procedure. One can either provide a moderate general illumination and reënforce it by portable lamps placed upon desks or tables, or one can provide a general working illumination all over the room. With the scanty outlets commonly provided the former course is the easier, and there is no objection to following it, except in rooms of the larger class. In these one often sees a veritable network of lamp cords, very unsightly, and very much in the way. In addition to this disadvantage, it is almost impossible to provide enough lights for a considerable group of tables and desks without seriously inconveniencing some of the workers through the glare of their neighbors' lights. It is sometimes, therefore, highly desirable to resort to general illumination, which can be carried out successfully

and economically if the outlets and desks or other working spaces can be conveniently arranged.

The main difficulty in general illumination is not physical but psychological. Those who have habitually worked with badly placed and ill-shaded individual lights have found by experience that under these conditions a great deal of light is necessary in order to enable them to see. The eye is working under very disadvantageous circumstances, and is dazzled by the glare, which has to be reënforced, so to speak, in order to leave enough residual light by which to see. Now this experience becomes almost an obsession, so that the worker forms a settled opinion that he or she can get adequate light for seeing only by using a large lamp equipped with a powerful reflector thrust immediately down over the work, and draws the further conclusion that any lamp which is not powerful and not close to the work cannot give adequate illumination. Hence, when an attempt is made to change from individual to general lighting, there is almost always a violent complaint that the lighting is insufficient, although in point of fact it may be more than adequate for the work and very much easier on the eyes than the illumination that it has replaced. After some experience in working with general illumination the eye gets accustomed to its conditions and works with much less effort even with materially lower illumination.

Nearly all classes of clerical and office work can be performed easily under an illumination of 3 to 4 foot-candles. In rooms where bookkeeping is carried on to a considerable extent the larger figure mentioned is about right, while the more ordinary office occupations can get along admirably with 3 foot-candles or even a little less. The exception is made in favor of bookkeeping because men at work on ledgers and filing slips usually write with fine pens for economy of space and with ordinary office ink of a somewhat bluish cast as it flows from the pen. The combination is a bad one from the standpoint of lighting. In cases where general illumination is not attempted and individual lamps are used in addition to a general groundwork lighting, the latter may conveniently be between 1 and 2 foot-candles, with desk lamps sufficient to bring the lighting on the work to a point not exceeding 4 or 5 foot-candles. Running above this is totally unnecessary and is apt to be trying for the eyes. Whichever method is adopted, all the lights, both those furnishing general illumination and those

lighting the work for individuals, should be thoroughly screened so that they cannot shine into anybody's eyes.

Lighting really large interiors differs in several important respects from ordinary practice as applied to rooms of the medium sizes just considered. In the first place, the aid received from diffusion from the walls is much less than in the case of smaller rooms, as has already been indicated. The experiments of Fontaine indicate that within moderate limits the light required is determined by the volume of the space to be illuminated, rather than by the floor space.

Since, however, the only physical effect of the increased height is to increase the mean distances of the diffusing surfaces and especially the ceiling from the radiants, the change could, in point of fact, alter only that part of the total illumination due to diffused light, provided that with increased height of ceiling the radiants are not themselves raised.

In large and high rooms there is a strong tendency to increase the height of the radiants above the plane of illumination, especially in case of using chandeliers, and this is the most important factor in the rule aforesaid. Obviously, in increasing the distance of the radiants one decreases the direct illumination approximately in the ratio of the inverse squares of the distances, and does not materially improve the diffusion.

Therefore the illumination falls off seriously. In a large and high hall, lights arranged in the ceiling or as a frieze, while often giving admirable effects, are quite uneconomical, and should be used, if at all, with a full appreciation of this fact.

In large buildings, too, the quantity of light required is subject to enormous variation, according to the purposes to which the building is devoted, and whether the whole interior must for artistic reasons be illuminated. In a ballroom an effect of great brilliancy is generally aimed at, while a room of equal size used as a factory needs strong illumination only where it will facilitate the work.

Again, in very large rooms the power of the individual radiants can advantageously be increased, and some sources of light inadmissible in domestic lighting, such as arc lamps; or to be used only with caution, like powerful mantle gas burners may be used very freely.

But in large buildings, as elsewhere, the fundamental purpose of the lighting is to produce a certain intensity at the plane of

illumination, which in such work should be assumed about 3 feet above the floor. The absolute illumination required may vary greatly, over a range, in fact, as great as from half a foot-candle to 3 foot-candles or more; but the lighting may properly be calculated from an assumed value, just as in the cases already discussed.

For purposes of discussion, we may first consider a hall 100 feet long by 30 feet high by 50 feet wide. The plane of illumination will then have an area of 5000 square feet, and the total volume is 150,000 cubic feet. And for simplicity we will assume 1 foot-candle as the minimum intensity to be permitted in any part of the space. Fig. 133 shows the plan of this assumed space. We will first take up the case of suspended radiants, which is the most usual method of treating such a problem.

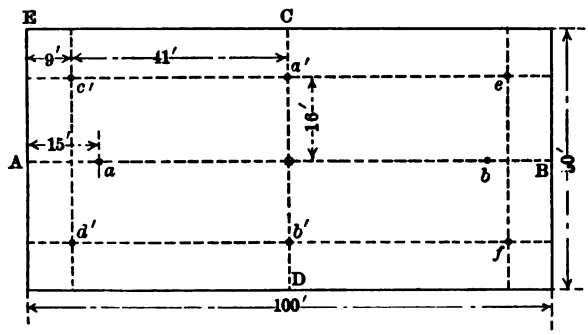


Fig. 133. — Plan of Hall.

Obviously, in a room of the shape given a single radiant is out of the question, on the ground of economy, since in meeting the requirement of a given minimum of illumination the most economical arrangement is that which exceeds this minimum at the fewest points possible. Two radiants give a possible solution, and are worth a trial. Clearly, they must be located on the major axis of the room AB; but since a corner, as E, is the most unfavorable spot to light, the radiants must be placed well toward the ends of the room. We will assume their height as 15 feet above the floor, and 12 feet above the plane of illumination.

Now the best place for the given radiant a is easily determined: it is such that, calling the projections of the points E and C upon the plane of illumination E^1 and C^1, $aC^1 = aE^1\sqrt{2}$, approximately. To fulfill this condition $Aa = Bb = 15'$ very nearly, and the two

radiants are at once located. In this case $d^2 = 994$, and since $C = Ld^2$, C should be practically 1000 candle power. Allowing $\left(\frac{1}{1-k}\right) = 1.5$, each of the radiants should be of about 666 candle power, a requirement which could be practically met by a nominal 2000-candle-power open arc, if its glare were not so forbidding.

Using incandescents, 42 of 16 candle power would be required in each group, which should be increased to about 60 if ground bulbs in a chandelier were to be used, since lamps so mounted interfere with each other's effectiveness to a certain extent. Reducing these figures to square feet per candle power, it appears that the assumed conditions are satisfied by allowing as a maximum about 3.75 square feet per candle power, or with allowance for properly softening the light, 2.6 square feet per candle power.

Lighting such a space from two points only is usually by no means the best way, and a much better effect would be secured by using six radiants. The same reasoning which led us to place a and b near the ends of the major axis of the room indicates a similar shifting in the case of six lights. From symmetry, two should be on the minor axis DOC, and as regards the projections of C and O on the plane of illumination, the best position for a radiant, located in the same horizontal plane as before, is at a', about 6 feet from C, with b' at a corresponding point on the other side of O. Now for the lateral pairs of lights. One of them may be approximately located with reference to E^1, and the projection of the middle point of the line to a', much as a' itself was located. This leads to a position c', 41 feet from a' and 9 feet from the wall. Forming now the equation

$$C = \frac{L}{n\left(\frac{1}{d^2} + \&c.\right)}, \quad d^2 = 306, d_1^2 = 1906,$$

and the sum of the other terms is little greater than the term in d_1^2. Simplifying thus, the candle power of each radiant comes out very nearly 235, without allowance for diffusion on the one hand or for ground bulbs and incidental losses on the other.

It therefore appears that the conditions call for 15 16-c.p. lamps in each of the six groups, a total of 90 as against 120 in the previous arrangement. The total rated candle power is then 1440, or 1 candle power for every 3.5 square feet. Six 250-

watt tungstens with suitable reflectors would very likely prove sufficient.

It is interesting to check this computation, based entirely on an assumed minimum illumination of 1 foot-candle, with the result of experiment. For large rooms, ranging from about 1000 to 5000 square feet in area, Uppenborn's careful investigations show that for good illumination 3 to 3.5 square feet per candle power is the amount required in practice. In most cases these large spaces are finished in light color, so that in spite of the high ceilings they are scarcely more difficult to light than ordinary dwellings. The absolute brilliancy required is determined by the purpose of the illumination, and the proper arrangement of the lights depends largely on architectural considerations. Oftentimes frieze and ceiling lights are used in halls, and their application to the case in hand is worth considering.

If arranged as a frieze, the lamps might be equally spaced around the walls, at about 5 feet below the ceiling, bringing them 22 feet above the plane of illumination. For simplicity we will assume the use of 90 16-c.p. lamps, with reflectors or their equivalent. Each gives approximately 27 candle power in its hemisphere of illumination. These lamps would be spaced a little more than 3 feet apart, giving 30 on each side of the hall and 15 on each end. Now, taking for examination the corner E^1, which is as unfavorable a locality as any, and roughly running up the illumination at this point, it falls a little short of 1 foot-candle, but a diffusion factor of 1.25 would carry it just about to the required amount. With lightly ground bulbs, which are far preferable to the clear ones in such a case, an increase to 36 lamps on each side and 18 on each end would be desirable, and 40 and 20 on sides and ends respectively would do still better. With the tungsten lamps now generally used the tendency is toward the use of larger units.

Lighting from the ceiling would lead to a slightly worse result. Lights so arranged, however, can give a very valuable groundwork of illumination when reënforced by lights more favorably placed. They have the advantage of being unobtrusive and of producing a generally brilliant effect, but give, if used to the exclusion of everything else, an illumination painfully lacking in *chiaro-oscuro*, a difficulty which is keenly felt in some forms of indirect lighting; and light directed almost entirely downwards is, moreover,

somewhat trying, suggesting a stage scene in the absence of footlights.

As has been already explained, the illumination at any particular point should have a predominant direction, else the effect on the eyes is apt to be annoying. A room lighted by brilliantly phosphorescent wall paper, for example, would produce a most disagreeable effect unless the luminosity were confined to one side, or, in general, to limited portions of wall.

Something of the same objection appertains to ceiling or frieze lighting when pushed to an extreme. In the room under discussion, the best general effect would probably be produced by combining pendent or bracketed lights with about an equal amount of illumination from frieze or ceiling lights.

Having thus obtained an outline of the lighting of a simple large area, we may, before passing to some of the special cases of large interiors, profitably take up one which practically is of great importance — the lighting of extensive and comparatively low rooms. This is one of the most frequent tasks which the illuminating engineer has to encounter. It is found in stores, in many factories and machine shops, in rooms employed for clerical work, and to a certain extent in ordinary offices. A typical case may be found in the lighting of a room, say 30 by 60 feet and no more than 10 to 12 feet in the story.

Here, then, is a room of some 1800 feet of floor space and of a height not much over one-third its width. Windows will usually be found only on one side of such a room, sometimes only on one end, so that ample provision has to be made for artificial lighting. The ceiling is generally light and the walls as generally relatively dark. The most typical case of this kind is where the space is used for clerical or general office purposes, for which strong and even illumination is necessary. The illumination required for such a room will be usually from 2.5 to 4.5 foot-candles on the working plane, the former figure for general office purposes, the latter for clerical work of a more trying kind.

Almost the first question which arises is the method by which the illumination can properly be calculated in a room of this kind. Obviously a considerable number of light sources will be used. To what extent do they all share in furnishing the illumination at a given point on the working plane? Some of the lights will be shining almost directly down upon the work, others

at a high angle of obliquity and therefore furnishing, according to the cosine law, only a small fraction of illumination. Theoretically, one is at liberty to integrate the light received at a given point on the working plane from all directions, but practically a large part of the oblique light is either cut off or ineffective. On the other hand, it does contribute to the general diffused illumination in the room. The useful illumination at a point, therefore, is materially greater than that obtained only from the nearby lights, but materially less than the theoretically integrated effects of all the lights. From a practical standpoint, the presence of these latter luminous sources is equivalent to raising the diffuse component of the light to a point somewhat greater than that which would be indicated merely by the coefficient of reflection of the surfaces applied to the lights really effective in direct illumination.

Experience shows that in dealing with rooms of this class under ordinary conditions of lightness of wall, one must supply light on the basis of 1.5 to 2 square feet per rated candle power. In other words, the room considered would require from 900 to 1200 candle power carefully installed under conditions of the best efficiency in order to reach the requisite degree of illumination, a little more if illumination for close clerical work is the chief object, a little less if the few points where especially good illumination is required are treated by the installation of desk lights. Ordinarily it is well to get along without individual lights upon a desk if possible, since in a large room, particularly if used by a considerable number of people, desk lights are a nuisance both from the multiplicity of cords required and from the fact that some of them are sure to be shining into the eyes of those not immediately using them.

The arrangement of the outlets must depend on the size of the units chosen, and somewhat on the arrangement of the working space beneath. The ground plan of the room in question is shown in Fig. 134 and the requirements generally would be well met by installing, say, 18 60-watt tungsten lamps 7 to 8 feet above the working plane, equally spaced on 10-foot centers. These lights should be in translucent reflectors of moderate angle, with the lower edges carried down far enough to prevent direct light from the unscreened filament from shining in the eyes of the workers. Most commercial reflectors fail in this particular, the lower edges being just too high for adequate protection. The writer has often

found it good policy, for example, in using the holophane reflectors, to install each lamp in the shade designed for the next larger size of lamp in order to get the requisite depth. The arrangement of lights here suggested is shown on Fig. 134 in the left-hand half of the figure. If, for instance, a wide center aisle is in the room, six 100-watt lamps would well answer the requirement, or for extreme cases six 150-watt lamps, as shown on the right-hand half of the figure.

This type of lighting is very commonly and successfully used in large offices and in shops. In the former case one has to look out rather carefully for the position of the working spaces to be illuminated. In a counting room, for example, it is generally

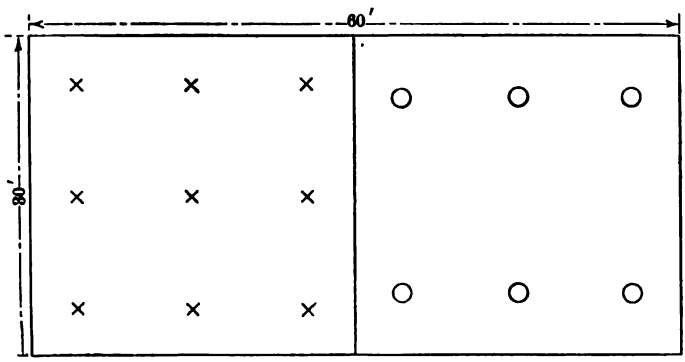


Fig. 134.

found that after the installation is complete there follow complaints, from some few desks, of insufficient light. When examined these are almost always due, not to insufficient light, but to wrongly directed light, some of the desks being in positions giving strong head or hand shadows, which prove annoying. A few very simple changes in the desk positions will nearly always remedy the trouble.

The case is an important one because outlets are commonly fixed before the use to which the room is to be put is determined. In designing outlets it is better to err on the side of too great rather than too small a number. Now and then conditions are such that some local lighting must be installed, but generally only to a very limited extent.

In the few instances where local lights are to be used to a considerable extent, it is best to make preparations for them by having an ample number of baseboard and floor plugs, and then to arrange the overhead outlets so as to provide a general illumination of perhaps 1.5 foot-candles to reënforce the desk lights. These latter should not be overdone. An 8-c.p. carbon lamp, or the smallest available tungsten or tantalum lamp, installed under a 7-inch or 10-inch green-flashed porcelain shade, is ample; and great care should be taken to avert the use of larger lamps, which are quite likely to result in eye trouble for the users from the glare on the paper if not from lights misplaced so that they shine into the eyes.

At this point it is pertinent to inquire concerning the use of indirect lighting in such rooms as those here under consideration. As already explained, indirect lighting can be carried out by two methods, — by concealing the light in coves or similar locations, or by installing the lamps in special fixtures adapted to throw the light on the ceiling for redistribution. The efficiency of the two methods is practically about the same, provided there is equal care in design. In either case the indirect lighting is much less efficient than the direct, as is necessarily to be expected from the circumstances in the case.

Assuming fairly light-colored ceilings and walls, experience shows that the light required with either indirect system for a given illumination on a working plane is nearly double that demanded for the same illumination from lamps lighting the space directly and equipped with suitable and efficient reflectors. Marks (Baltimore Lectures, Vol. II, page 702) indicates practically these figures, and the author's own experience confirms them. In one recent experience in the author's practice both methods were actually tried and the illumination and energy carefully measured. The direct installation was carried out with reflectors which were deep enough fully to protect the eyes. The ceiling and walls were fairly light in tone and the space was approximately 2500 square feet. With the direct system of illumination, the rated candle power of the lamps amounted to 0.24 candle power per square foot per foot-candle. With the indirect system under exactly the same conditions, the light required was 0.45 candle power per square foot per foot-candle. In general terms, with the indirect lighting nearly 1.8 times the candle power was required for the same effective illu-

mination. Cravath in a similar test in a smaller room recently obtained 1.76 for the equivalent ratio. Bearing in mind the fact that both coves and inverted lighting fixtures suffer much from dirt, it is well within bounds to say that under average conditions the indirect system requires about twice as much light as a well-planned direct system for equal illumination. The usefulness of indirect lighting is, therefore, rather special than general. When properly applied it is pleasant and effective, but never economical as compared with well-arranged direct lighting.

One may next profitably take up the equipment of such a room as shown in Fig. 134 when used for manufacturing purposes. The old method of lighting a space occupied by machines and workmen was to put an individual light shining directly on each machine or such part of it as needed special illumination, leaving the rest of the room in darkness. The result is what has come to be known as "spotted" lighting and the general results are usually bad. The strain on the eyes of the workmen owing to the constant transition from bright light to darkness as the eye shifts from the work to the space beyond is exceedingly trying, much in the same way that sudden and violent flickering of light is trying. More than this, there are very often intensely bright reflections from parts of the machine or work, which dazzle the eye, cause the pupil to contract, and interfere very seriously with efficient vision. It has not infrequently been found that workmen complain of insufficient light under such circumstances when the actual intensity on the work is two or three times that needed on the most liberal estimate for proper vision. In fact, the more light the more dazzling the effect, and the less effective the vision obtained.

The remedy for spotted lighting is diffusion, but in buildings used for manufacturing purposes a general illumination such as indicated in Fig. 134 is not often easy to apply. Considerations of economy make it undesirable to light at maximum brilliancy certain parts of the room, since these parts may be used only for storage, for passageways, or for rough work requiring no strong illumination. The problem, therefore, reduces itself to lighting all parts of the room efficiently for their uses, and this frequently implies lighting special machines with considerable brilliancy while leaving the general illumination low. The secret of success is so to distribute the light as to leave no dark corners and no dark regions upon which the eye has to fall, while yet providing at the

points needed sufficient light for the most critical work that has to be done.

This can best be accomplished by using local lighting at the machine plus a general illumination to relieve the contrast of darkness and light and to furnish for general purposes a groundwork lighting. This end may be reached by the installation of lights with translucent shades which permit part of the light to pass through for general use, while the rest is directed upon special operations which require light. The only difficulty with this procedure, which may be carried out by lights with shades of opal glass or of prismatic glass with diffusing surface, is that translucent reflectors are fragile and in some cases breakage would be a serious item. The same result can be attained by using comparatively small lamps in suitable reflectors placed near the work and adding general illumination from lights equally spaced over the ceiling on cords or short stems. The general lighting obviates most of the spotted effect which is so unpleasant, but equally essential is the reduction of the extreme intensity produced by local lights under ordinary conditions. The space shown in Fig. 134, when used for ordinary manufacturing purposes, will require on the whole about the same amount of light as already indicated, but about one-third of that light should be devoted to general illumination, the remainder being distributed over the machines.

Lighting machines is a task standing somewhat by itself, because while the total amount of light is generally moderate, it must be directed where it will do the most good, and machines often have projecting arms or other parts which throw strong shadows and interfere with the proper observation of the work. Sometimes conditions can best be met by small lamps, usually not over 8 candle power, with reflectors directing the light where it will do the most good. In other cases the lights can best be placed directly over the machines, or sometimes with diffusing screens behind the machines, the main point being that, while from 3 or 4 up to 8 or 10 foot-candles may at times be necessary for the work, the light should not be placed so as to throw the work into shadow or to cast bright reflections into the eyes of the workman. In some instances indirect lighting can be resorted to, utilizing the light ceiling and walls to the utmost. It should be used, however, only when a reduction of shadow is desired with but a moderate degree of illumination. The long and short of it is that manufacturing

spaces must be treated symptomatically, bearing in mind the necessity of enough generally diffused light to prevent the spotted effect.

Occasionally one encounters intricate machines extremely difficult to light, and one then has to resort to unusual means. A recent case in the writer's experience was the illumination of the drying rolls of a paper mill, which after considerable experiment was successfully carried out by seeing to it that the interior of the hoods over the rolls was painted a good white and then hanging mercury arcs within the hood, the mechanism being left outside and the tubes themselves being suspended 3 or 4 feet below the top of the hood with a free opportunity to radiate light in every direction. Such a combination of direct and indirect light cuts off all sharp shadows and allows one to see in and about the parts of a complex machine very easily. These, however, are special cases. In the majority of instances a general illumination of 1 foot-candle or thereabouts plus 3 or 4 foot-candles in the vicinity of the work gives good results in industrial lighting.

EFFICIENCIES OF UTILIZATION.

Concentrating reflector	.73
Concentrating prismatic	.76
Concentrating mirror	.88
Diffusing reflector (dense)	.44
Diffusing reflector	.53
Diffusing reflector	.63
Diffusing reflector	.48
Diffusing reflector	.50
Diffusing reflector	.53
Diffusing balls	.35
Diffusing balls	.36
Diffusing balls	.34
Half-globes, prismatic	.51
Coves, indirect	.36
Coves, indirect	.15
Indirect	.28
Indirect	.29
Indirect	.35
Semi-indirect	.38
Semi-indirect (inclosed arcs and diffusers)	.49
Arc with opal globe	.45

As a guide in designing the illumination of rooms, large or small, presenting no extreme features in the height, shape, or finish, a convenient figure to remember is that with lamps arranged at ordinary heights near the ceiling and equipped with well-designed diffusing reflectors, one can count on receiving upon the working

plane 4 or 5 foot-candles per rated candle-power-per-square-foot. This implies that about 50 to 60 per cent of the total flux of light is utilized on the working plane, the rest being taken up by absorption and unutilizable reflection. The table on page 245, derived mainly from the writer's own experience, gives the actual efficiencies of utilization reached in lighting installations with various types of shades and reflectors.

These figures will serve as a useful guide in computing the illumination by the flux of light method. It will be noted that the highest efficiencies are with somewhat concentrating prismatic or mirror reflectors arranged to throw as much as possible of the light flux upon the working plane without any material utilization of the diffusing surfaces of the room. The next grade of efficiency is obtained with diffusing reflectors of opal or prismatic glass which throw a large amount of the light downwards and yet transmit a material fraction which is rediffused by the walls. A slightly lower grade is given by the semi-indirect system, which rises in efficiency as more of the light-flux is sent directly to the working plane and less diffused from the ceiling. Of about the same efficiency are the lights inclosed in diffusing balls or globes, the thinner globes of course being the more efficient. Next in order come the purely indirect systems in which none of the light is sent directly to the working plane but all is diffused from surfaces which are as a rule none of the best.

Any one of the systems indicated can be made to give thoroughly good illumination and any one of them can be so misused as to be unsatisfactory. As between the ordinary direct and the indirect systems of lighting, the former when properly installed are always the more efficient. One interesting question which has arisen as between the direct and indirect schemes of lighting is the quality of the illumination as regards its usefulness. There is no physical or physiological reason why there should be any difference in the usefulness of a given illumination derived from either method of arrangement, assuming each to be planned with equal skill in the way of avoiding, on the one hand, glare from exposed sources, and, on the other, a perhaps equally troublesome glare from over-illuminated surfaces. There have been some strong expressions of opinion by those who have had a prejudice in favor of one or the other method. The first figures derived from actual experiment on the matter are those of Millar ("Trans-

actions Illuminating Engineering Society," Vol. II, page 583), which indicate that a given intensity of illumination derived from indirect lighting is materially less effective than when derived from direct lighting. On the other hand, some recent observations by Cravath indicate exactly the reverse, based on judgments made like Millar's by a group of independent observers. The psychological and casual physiological factors in the case are, however, so uncertain and variable that it is unsafe to generalize from either of these diverging statements. In the author's opinion, whatever differences have been observed are due to secondary rather than primary causes, and must disappear when the installations are really skillfully planned. The difference in efficiency of utilization is, however, unavoidable.

Where merely rough work is being done, arcs may be effectively used, always, however, shaded by ground or similar globes. These are distinctly cheaper, because more efficient, than carbon incandescents, but their light lacks the steadiness desirable for work requiring close attention. Six 350-watt arcs would give, in the room shown in Fig. 133, very good illumination, when placed in approximately the positions deduced for the six clusters, with a total expenditure of 2100 watts as against about 4500 watts required by the clustered incandescents, and, say, 3600 watts required by about 36 pendent 32-c.p. lamps. In many cases, less light than this would be required, and the total amount of energy could be correspondingly reduced. As already indicated tungstens would do even better.

From Fig. 133 it appears that in using arcs about 2000 to 2500 square feet may be assigned to each 500-watt arc, and 1000 to 1500 square feet to each 350-watt arc. It should be remembered that the inclosed arcs with inner globes are nearly 25 per cent less efficient than this, although to be preferred by reason of their ordinarily greater steadiness, and that alternating arcs are slightly less efficient than continuous-current arcs.

Arcs do their best work when placed fairly high and used in cases where protracted close attention on the part of the workmen is not necessary. They are preferable to incandescents of any kind when colored objects are to be illuminated.

In workshops where special objects are to be illuminated, arcs are at a great disadvantage with respect to the distribution of light, since their relatively small number forbids placing them

in the most advantageous positions with respect to all the machines.

They have, in short, the disadvantage of being radiants too powerful for the best distribution. It is thus found that in practical illumination arcs are considerably less efficient than their actual candle power would indicate. The effect of the bright radiant upon the eyes, the rather dense shadows, and the slanting light at a distance from the arc, unite to produce results that cannot be predicated from photometric measurements alone.

For example, a 350-watt open arc is, in point of mean spherical candle power, closely equivalent to ten 32-c.p. incandescent lamps; but in an actual installation indoors there are few cases in which the arc could not be replaced by six such incandescents without detriment to the illumination. With tungsten incandescent lamps at 1.25 watts per rated candle power, the ordinary carbon arc compares unfavorably except in cases where its whiter color is important. For such cases the intensified arc should generally be used.

If strong illumination is the object to be attained, there is little doubt that for gas lighting in rooms of the size considered, mantle burners should invariably be used. As already intimated, each such burner of the ordinary size is equivalent to about two 16-c.p. distributed incandescents. If the lamps are grouped in each case, the mantle burner must be given a rather better rating, being equivalent to between 2.5 and 3 such incandescents. Properly shaded, the mantle burner is a very economical and effective illuminant.

For lighting large areas, like those we have been considering, it is very well adapted, but if the lights are placed high it is necessary not only so to shade them as to hide the mantles, but they must, in addition, be furnished with such shades or reflectors as will throw the light effectively downward. Reflectors or holophane globes used with the mantle burners will correct this faulty distribution and enable them to be used more effectively in the case in hand. The modern inverted Welsbachs diminish this difficulty and give excellent results, but even with these it is necessary to use diffusing reflectors to shade the eye and improve the distribution.

With higher rooms than usual, one can concentrate the radi-

ants more advantageously, and has considerably more liberty of action in placing the lights.

Fig. 135 is intended to illustrate the conditions which exist in a very high room of fairly large area. It shows in vertical section a room supposed to be 50 feet square and 50 feet high, the plane of illumination, *ab*, being 3 feet from the floor. We have here 2500 square feet of floor surface. At the ordinary rate of 3 square feet per candle, this would demand 833 candle power,

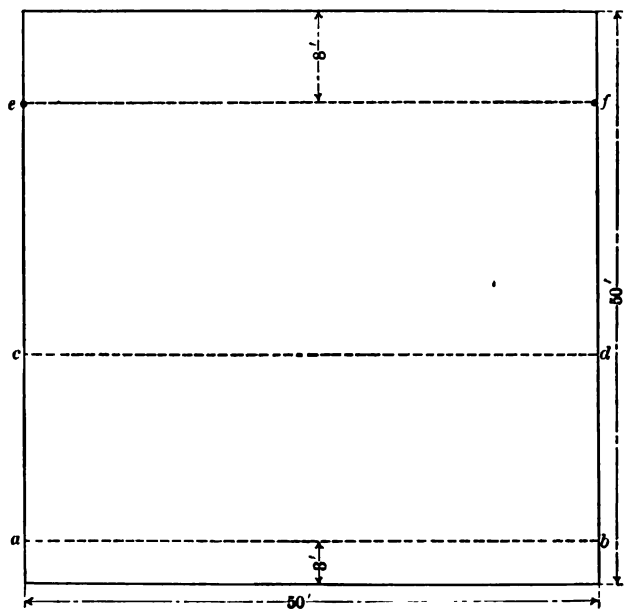


Fig. 135. — Vertical Section of Hall.

or practically 52 16-c.p. lamps, or, with a coefficient of diffusion of 1.50, about 36 such lamps.

But the previous calculations having been made for a room only one-half this height, and with lamps placed considerably below the ceiling, it is clear that the greatly increased height in the present case will lead to somewhat different conditions unless the lamps are to be dropped very far below the ceiling — so low as to produce a decidedly unpleasing effect. Lamps placed, for example, in the plane *cd*, corresponding to frieze lamps in the

previous instance, are too low to look well, while they would, on the basis just given, furnish the room with satisfactory illumination. If placed on side brackets at or below the plane *cd*, they would work well on the floor, but would produce the effect of the ceiling fading into dimness unless the ceiling itself had an extremely light finish.

Such a room, therefore, while very easy to light thoroughly, is very difficult to light both thoroughly and with good artistic results. Rooms of such dimensions are seldom used for manufacturing purposes, these shapes occurring more frequently in rooms for public uses of various kinds.

Without going into detailed computation, which the reader can readily make for himself, in the light of previous work on Fig. 134, it is safe to say that often the best general effects would be produced by placing perhaps one-third of the total candle power in lamps of moderate candle power, as a frieze or in clusters, 8 or 10 feet below the ceiling, in the line *ef*, or thereabouts, and putting the remainder on brackets, in groups of three to six, a little below the plane *cd*. Such an arrangement obviously loses somewhat in the efficient disposition of light, on account of the great height of part of the lamps, which can be depended on only for a rather faint groundwork of illumination on the plane of illumination *ab*. If, for example, the total installation consists of 600 candle power, of which 200 is in the frieze, the mean distance of the frieze lamps from a point, say, in the middle of the floor, would be in the vicinity of 45 feet.

Consequently, allowing for the effect of the reflectors of the frieze lamps, and for what each can do by diffusion, it is safe to say that the frieze lamps would give an illumination of not over one-fifth foot-candle on the plane of illumination. Hence, something like eight-tenths foot-candle would have to be furnished by the lights upon brackets. The amount of light furnished by these would, therefore, have to be about eight-tenths of the total illumination, as determined by lights placed in the relative position shown; that is, the ceiling lights of one-third the total candle power really would be furnishing not over one-fifth of the total light, which means that for lights placed as just indicated the total candle power installed should be increased somewhere from 25 to 33 per cent, or rather more, as the bracket lights cannot always be conveniently placed in favorable situations.

Hence, in a room so illuminated, it would not be safe to allow more than 2 to 2.5 square feet of floor space per candle power, and generally nearer the former figure than the latter. To attempt the lighting of such a room by frieze or ceiling lights, as ordinarily placed, would be wasteful. If economy is not an important factor in designing the illumination, at least half the lights might be placed in the frieze with a distinct gain in artistic effect. In such case the total installation should be fully 50 per cent greater than the minimum required. We shall see, however, that there are effective methods of getting a strong groundwork illumination from above without resorting to either of these methods.

To follow up the effect of raising the lights in a high room still further, it is well to note that the critical point is the amount of available diffusion. If one were dealing with a room lined with black velvet, or with translucent walls, in which there is only a very minute amount of diffused light, raising the lights would diminish the illumination quite nearly according to the law of inverse squares, assuming unshaded or similarly shaded lamps.

Writing now K for the coefficient of diffusion denoted by the fraction $\left(\frac{1}{1-k}\right)$, and recurring to the formulæ previously given for illumination, we have at once $KC = Ld^2$, and for fixed values of C and L, $d = P\sqrt{K}$, where P is a constant. Hence we may conclude that for any desired value of the illumination with a fixed amount of lights available, the height to which these lights can be raised and still produce the required effect is approximately *proportional to the square root of the coefficient of diffusion.*

The moral of this is tolerably obvious. If one deals with a dome finished, let us say, in white and gold, it may be permissible to place a large part of the lights fairly high up, while in a church with a vaulted roof in dark oak and with dark walls, lights placed high are nearly useless for purposes of illumination. In such a case, lights placed at the level of the roof beams and unprovided with reflectors have barely more than a decorative value, and should be treated, if used at all, essentially as a decorative feature, useful for bringing out the details of the architectural design.

Any real illumination must be accomplished by lamps with reflectors or by lamps placed down nearer the plane of illumination. In these dark interiors lamps with reflecting shades can be used to especial advantage, since the coefficient of diffusion is so small that

the lessened diffusion due to the partially directed beams from reflectors is of trivial consequence. In fact, there are few cases in which reflectors cannot be used to advantage in rooms having very high ceilings.

Churches are generally badly lighted, and are, in fact, rather difficult of treatment, if of any considerable size. They are seldom brilliant in interior finish, usually have rather high vaulted roofs,

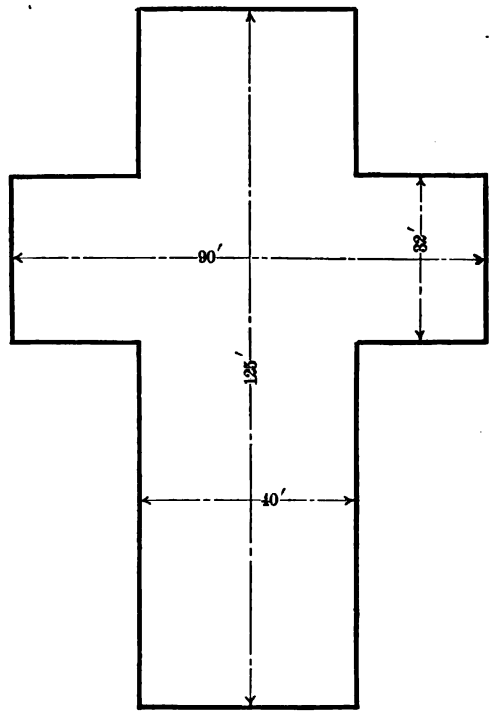


Fig. 136.

and require fairly good reading illumination. The few cases in which their form approximates to Fig. 134 may easily be treated as there indicated, but such is not the usual condition. Fig. 136 gives a roughly typical church floor plan as regards the main body of the building. The total floor space is shown as 5000 square feet in the nave and choir combined, and 800 square feet in each transept. The walls are assumed to be 30 feet high in the clear, with a Gothic roof above. Now the total area to be lighted is 6600

square feet, and the value of K is low, not safely to be taken as exceeding 1.20. The peculiarities of the building, as a problem in lighting, lie in the high walls and the absence of any ceiling, both of which complicate matters.

As to the nature of the radiants, when electric lights are available one must depend almost entirely upon incandescents. Arc lamps are not to be considered for artistic reasons, save, perhaps, in indirect lighting of the choir. If only gas is available, mantle burners suitably and thoroughly shaded had better be the main reliance, as ordinary gas flames are seldom steady in such a place. In either case it is generally wise to avoid chandeliers. The only

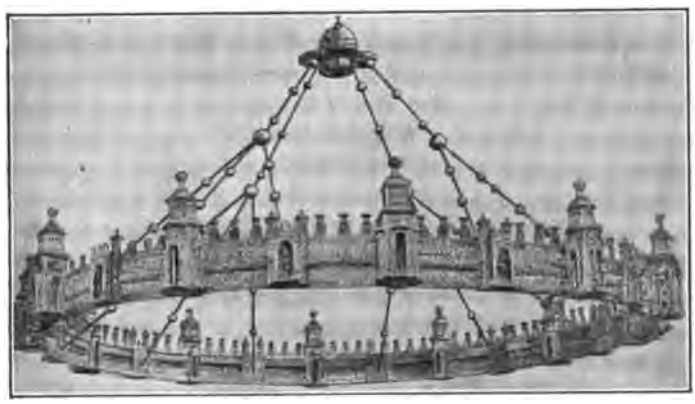


Fig. 137.

form of chandelier for which there is good historic reason in Gothic churches is the great *couronne*, like those found at Hildesheim and elsewhere, originally symbolic of the Heavenly City, and exceedingly ornate, having, therefore, the excuse of an intentional decorative and ecclesiastical value. Fig. 137 shows the Hildesheim *couronne*, which has recently been fitted with incandescent lamps.

As to the amount of light needed, it would be advisable to allow no more than 2.5 square feet per candle power, which, taking K at 1.20, would call for 2200 net candle power. In point of fact, in using electricity, not less than 150 16-c.p. lamps or their equivalent should be used, and even this number, on account of the trying conditions, would have to be very deftly arranged to give the required result. For the best effect they should be chiefly

lamps with diffusing globes, assigned about as follows: 90 to the nave, 20 to the choir, and 20 to each transept. As to position, the most efficient method would be to put them in groups of six or eight on brackets between the windows, at half to two-thirds the height of the wall, with possibly larger groups massed at the four corners of the crossing. With still more lights available, very beautiful results could be attained by adding lights at the capitals, and, in some cases, along the tiebeams, or on the corbels from which the pendent posts rise. These latter arrangements are very effective, but not economical, and if used should be installed on the basis of about 1 candle power per 2 square feet of floor surface. With the large tungsten units the number may be proportionally smaller, which simplifies the fixture design. All incandescent lamps used without diffusing shades should have ground bulbs.

The chief point in church lighting is to furnish modest reading illumination, say 1 to 1.5 foot-candles, without glaring sources in the eyes of the congregation and without breach of the architectural unities of the place. The treatment must be almost entirely guided by the individual situation, and is often hampered by the existence of fixtures or particular developments of methods which cannot well be gotten rid of. Now and then standards, bearing clusters of lamps, are installed throughout the nave of a church, and occasionally these standards are good enough to make their retention desirable. By fitting them with small incandescent lamps within small diffusing globes very pleasing results can sometimes be reached. As a rule, lights should not be carried high in churches. The mediæval church, closely copied in many modern interiors, was a place where little light was necessary, and that little was needed in the lower body of the church, the towering roof gaining rather than losing in effect by fading into obscurity above. Then, too, most worshipers either were unable to read, so that they needed no reading illumination, or knew the service, so far as they were required to know it, by heart, so that again light was unnecessary.

In modern churches and forms of worship these conditions have so changed that a good reading illumination is necessary, as has been before remarked, but it is not generally furnished. In fact church fixtures, on the whole, are the least adapted to their use of any that can be found even by patient searching. The mischief is generally done by stupid and slavish following of inappropriate

precedents. The lighting of the Mosque of St. Sophia in Constantinople has probably been responsible for more badly illuminated churches than any other one malign influence. The lighting fixtures in this famous building are shown in their general bearing in Fig. 138. They consist of spreading wrought-iron and bronze fixtures carrying numerous tiny oil lamps, not far over the heads

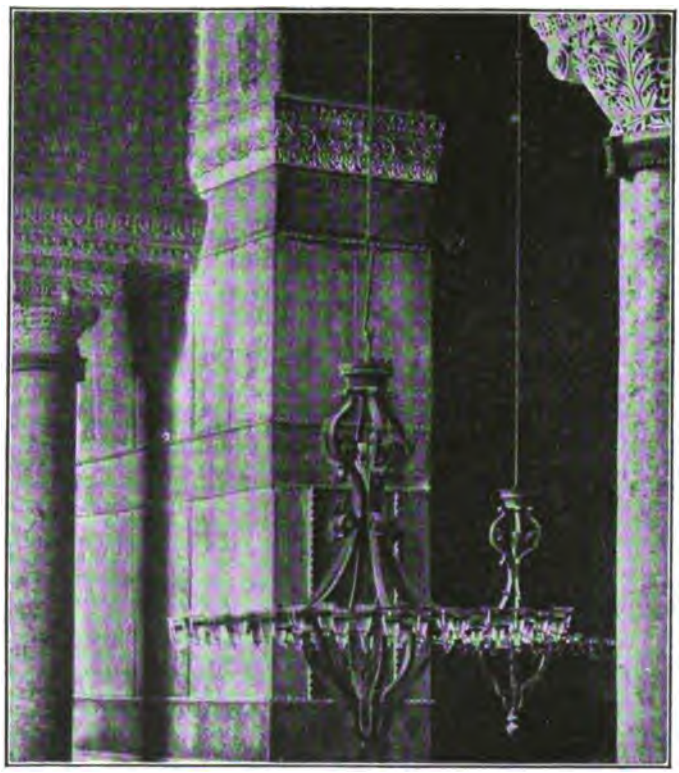


Fig. 138.

of the worshipers — about 9 feet from the floor. Each fixture is borne by a preposterously long rod hanging from the huge and lofty central dome, a method of support made necessary by the extraordinary proportions of the building and the conditions of its use. This kind of fixture has been in use there for centuries. But whatever venerable association may consecrate it now in the eyes of Christian and Mohammedan alike, there is no possible

propriety in copying so clumsy a device in modern churches of different architectural character, with all our present illuminating resources at hand.

In the hands of the Occidental barbarian, this type of fixture usually degenerates into a short bronze or iron barrel, within which is ill concealed a group of glaring incandescent lamps throwing their light into the eyes of the just and unjust alike, and giving a maximum of glare with a minimum of illumination. The only possible method of reducing the glare is so to inclose the lights as to give almost no illumination, and this has also sometimes been done, less through design than through sheer stupidity. The writer calls to mind at least a dozen churches in which such fixtures are conspicuously useless, and, he may add, has had the pleasure in several instances of throwing them out and replacing them by devices less offensively glaring and far more effective.

The nave and the transepts of a church may be easily lighted in accordance with the methods earlier suggested, preference being given to that which lends itself most harmoniously to the architectural requirements. Above the side aisles it is often desirable to use lights with small diffusing globes, placed close to the ceiling, although sometimes the height is sufficient to enable brackets to be used, if also employed for the main work of lighting the nave and transepts.

The sanctuary is a different matter. In churches having an elaborate ritual bright lighting here is desirable, especially in connection with the altar. Generally there is an opportunity for placing lights behind the chancel arch, either above, or at the sides, or in both situations. Where the available space permits, such lamps can with great advantage be furnished with somewhat concentrating reflectors arranged to flood the sanctuary with light when desirable, and particularly so to illuminate the altar as to bring out its full decorative value. Sometimes it is desirable to specialize the lighting for these two functions, so that the altar can on occasion be thrown into striking prominence. It must not be forgotten that most elaborate altars should not be lighted uniformly from the front, inasmuch as this tends to suppress the detail, which is often their chief charm. To avoid this difficulty, lights with focusing reflectors can be massed on one side of the space behind the chancel arch so as to illuminate the altar at any required angle, leaving enough general illumination to prevent too

dense shadows. The particular arrangement of course depends on the special things which it is desired to bring into prominence.

The lights in the sanctuary should be upon several switches so arranged as to secure any requisite intensity of illumination for the various cases which have to be met. Where candles are freely used in connection with the ritual, the question of replacing them by incandescent lamps frequently comes up. Decorative standards used around the altar can often be fitted for small-bulb, heavily frosted incandescents with good effect, but where the candle has a symbolic value in the ritual such a substitution is in very dubious taste. One recoils from the thought of the Tenebræ with the candles turned off by snap switches on the wall.

Suitable illumination for the reading desks goes almost without saying. It should be given by carefully shielded reading lights serving the purpose of their use without attracting any further attention. Non-ritualistic churches having the form of a large hall require the lighting appropriate to that case, and do not involve any of the special problems inherent in other churches. The question of stained-glass windows is one which sometimes arises as a problem in illumination. Comparatively little has been done in this matter save in isolated cases, but there is no reason why, if thought desirable, the chief windows may not be illuminated from the outside by indirect lighting. In this case arcs are by far the most convenient source of light, since they alone of common illuminants give a light sufficiently rich in blue to bring the stained glass to its daylight value. In cases where there is strong daylight lighting from a dome, it may be desirable by indirect illumination to bring the interior at night to something approaching the condition best suited to displaying it by day. Aside from such uses as these, the arc light has no place in a church, although even flame arcs have been used, by a combination of bad taste and bad judgment, for church lighting.

In lighting with gas, brackets are about the only thing feasible, since the flames must point upward, and few capitals would fail to look overloaded with adequately shaded burners. Mantle burners, of course, do the work most efficiently, but used alone the effect is certain to be grimly utilitarian; and especially around the choir small ordinary jets may be used to very great advantage. The mantle burners should be as unobtrusive as possible in such a case, even if they do the main work of the illumination.

Only the barest hints can be given for the detail of church lighting, as so much depends on the architectural peculiarities and on the scheme of decoration, but the foregoing indicates the general principles to be followed. The most important thing is to give a rather moderate illumination without the individual radiants obtruding themselves unpleasantly on the eyes of the congregation.

Large public buildings are generally easier to light than churches, since they are, as regards the shape of the several rooms, comparatively simple and are seldom dark in finish. Many rooms may be illuminated along the lines already laid down, but, on the whole, powerful radiants, such as arc lights and the largest tungsten lamps, may be more freely used here than elsewhere.

In very high corridors and high halls without galleries arc lights can be used with excellent results. They should invariably be shielded by ground or opal globes, and, if hung very high, as is generally desirable, to keep them out of the ordinary field of vision, should be provided with reflectors. They should be numerous enough to suppress the shadows that ordinarily exist under the lamps. From the absence of such shadows the modern intensified arcs have a very material advantage.

Rooms lighted by arc lamps ought to be of light finish, since the lamps must be placed rather high to keep them, even shaded, from glaring unpleasantly; and they give a strong, nearly horizontal beam, which, in lack of good diffusing surfaces, is for the most part wasted. Reflectors deep enough to turn this downward would usually be most unsightly and would give an unpleasant searchlight effect, which should be avoided.

Never let the eye rest simultaneously on arc and incandescent lamps indoors, since the latter seem very dim and yellowish in such company, and will never be credited with anything like their real brilliancy. Similar reasoning applies to the use of mantle burners and ordinary gas jets in the same room. When so used the former should be well shaded and unobtrusively placed, and the latter massed and generally unshaded or lightly shaded, so as not to seem of relatively very small intrinsic brilliancy.

Sometimes in large interiors the powerful regenerative burners and high-pressure mantle burners may find a place. They give an excellent downward illumination, which is occasionally very useful.

Theaters present some very interesting problems in illumination

on account of their peculiar shape and the difficulty of lighting the interior with sufficient brilliancy without making the radiants altogether too conspicuous. They are, as a rule, more brightly lighted than other interiors, but seldom judiciously. The usual fault is to place the lights so that they shine directly in the eyes of a considerable part of the audience. The auditorium is commonly very high in proportion to its area, and plentifully supplied

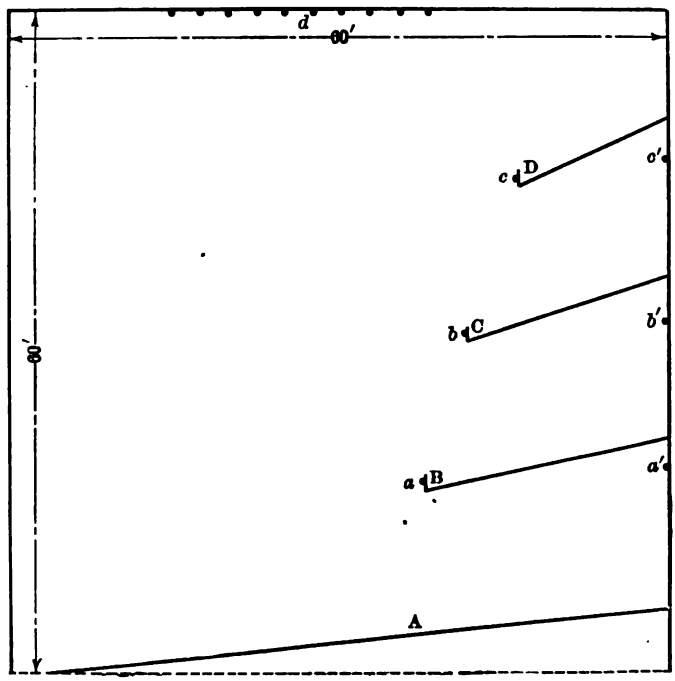


Fig. 139. — Elevation of Theater.

with galleries. Fig. 139 shows the typical elevation, the floor plan being generally only slightly oblong. The galleries, of course, sweep around the sides, narrowing as they near the proscenium boxes. Not infrequently a fourth gallery is added.

During the acts no very considerable amount of light is needed, but between them it is generally desirable to produce an effect of great brilliancy. The main floor is far below the roof, and the shelving galleries render it difficult to light the spaces between them. The general fittings are usually light, but the dull

hue of the floor and galleries when occupied kills much of the diffusion.

The actual floor space to be dealt with as a problem in illumination includes the galleries, and hence greatly exceeds the area of the main floor. Assuming the width in Fig. 139 to be 50 feet, the nominal area in front of the footlights is 3000 square feet. The total gallery area is usually from 1 to 1.5 times the floor space, so that the entire space to be lighted would be at least 6000 square feet, half of it being located so that it can get little advantage from the illumination of the main space above the floor. The space behind *A*, and the galleries *B*, *C*, and to a less extent *D*, have to be treated almost as separate rooms, particularly when, as sometimes happens, the galleries are rather lower than shown in Fig. 139.

This is the main reason for the apparently abnormal amount of light that is needed in theaters. The fact is that there is really a very great area to light, and it is so placed that it cannot readily be treated as a whole. The following table shows the approximate amount of illumination furnished in a number of prominent Continental theaters.

If in Fig. 139 we allow, on account of the high ceiling and conditions unfavorable for diffusion, 2 to 2.5 square feet per candle-power, and take account of the real total floor space, including the galleries, we reach just about the figures given below, which are based on the floor plan only. And in practice 3600 candle power would probably do the work well, although, since this only allows ordinary good reading illumination, more light is necessary to give the really brilliant effect which is usually desired. Fully 5000 candle power would be required to show off the house effectively.

Theater.	Sq. Ft. per C.P.	C.P. per Sq. Ft.
Opéra, Paris	0.78	1.28
Opéra, Paris, as ballroom	0.38	2.63
Odéon, Paris	1.52	0.66
Gaieté, Paris	1.14	0.87
Palais-Royal, Paris	0.51	1.96
Renaissance, Paris	0.52	1.92
La Scala, Milan	1.07	0.93
Massimo, Palermo (ordinary)	0.86	1.16
Massimo, Palermo (en fête)	0.53	1.88

As to the location of the lights and their character, the body of the house can be usefully lighted by lamps ranged along the galleries at *abc*. If these are placed below the edges of the galleries, they will glare directly into the eyes of the spectators, so that it is

better to illuminate the gallery spaces from the rear and above, at *a'b'c'*. The radiants may well be provided with reflectors, as the diffusion amounts to little, and all lamps on and under the galleries should have ground globes. These lights may be reënforced to great advantage by ceiling reflector lamps, best sunk in the ceiling deep enough to make them inoffensive from the galleries. These, with some ornamental lighting about the stage and boxes, should give a capital result. The main point is to light the interior brightly without thrusting bright radiants into the field of vision.

A useful form of ceiling lighting, applicable to many very high interiors, is arranged by replacing the lamps at *d*, Fig. 139, by opal-glass skylights of rather large dimensions, and placing above them arc lamps with reflectors. The skylight surfaces should be flat or slightly projecting rather than recessed, and the reflectors should be planned so that each may throw a cone of light subtending an angle equivalent to the whole floor plan.

By thus superposing the indirect illumination from a group of lamps the general steadiness of the light is greatly increased. In thus using arcs, care should be taken to have the diffusing skylights faintly tinted so as to lessen the color contrast between the powerful ceiling lights and the incandescents used elsewhere in the house. It is a considerable advantage thus to place lights above the ceiling, as it avoids the serious heating effect due to massing incandescents near the ceiling of a generally overheated room.

On account of this heating the use of gas in theaters is highly undesirable, and has been almost completely abandoned. In lack of anything better, fair results could be reached by mantle burners placed somewhat as shown in Fig. 139, and very thoroughly shaded by holophane or other diffusing globes, much of the illumination being located above the ceiling.

The Lighting of Schoolhouses. — The lighting of schoolhouses stands somewhat apart from the ordinary illumination of large interiors on account of the exceptional uniformity desirable and the severe requirements of lighting adequately a large number of working spaces arranged in an entirely formal way. First-class illumination must be provided for usually about forty pupils, and it must be so arranged that there is no trouble from shadows of head or hand upon the work, while each pupil must get this

adequate and well-directed lighting when sitting in a comfortable position.

In rooms used for general clerical purposes, as has been indicated, the usual difficulties may be eliminated by slight changes in the positions of the desks or by turning them around. This is not permissible in a schoolroom, where the desks are fixed in an orderly manner. Moreover, the light must be very carefully kept out of the children's eyes, and glare, either direct or reflected, must be carefully avoided. As to the amount of illumination required, it must be sufficient for very easy reading and writing, the amount depending somewhat on the class of work to be done and the sort of books used. A minimum of 2 or 3 foot-candles is imperative. For the ordinary class exercises the former amount as an irreducible minimum serves well, since the average is likely to run well over this figure.

In case of work with textbooks of more than usually fine print or with Greek or Gothic type, this minimum should certainly be raised, and the author is inclined to agree with Dr. Broca that 3 to 4 foot-candles is a better minimum figure, especially if critical work is to be done and the hours of artificial lighting are relatively long, as, for instance, in the case of rooms used for evening schools. The cost of such an increase is trivial, and with well-distributed and well-diffused illumination it is far safer to err on the side of a high minimum. In some special cases where manual work of a somewhat trying character is being done, not less than 5 foot-candles is desirable.

In 1907 the Boston School Committee appointed a committee of three oculists and two electricians to examine into the condition of school illumination and report to the committee. The author had the honor to serve this commission in a consulting capacity and took part in the experiments tried.

The standard Boston schoolroom is about 26 by 30 feet, with a 13-foot ceiling, and usually contains 42 individual desks besides the teacher's desk on a raised platform. Daylight illumination is obtained from windows on the left of the desks as the pupils sit. The woodwork is usually a light yellowish color, the walls of a faint green or buff, and the ceiling white. The coefficient of reflection of the walls, when clean, is usually about 0.45. A spare schoolroom was fitted up for experimental purposes and a large amount of time was spent in trying the effect of various

arrangements of lights and various types of fixtures. The final outcome is shown in Fig. 140. At each of the designated spots a 40-watt tungsten lamp was suspended 10 feet 6 inches from the floor in the diffusing reflector shown in Fig. 141, a simple chain

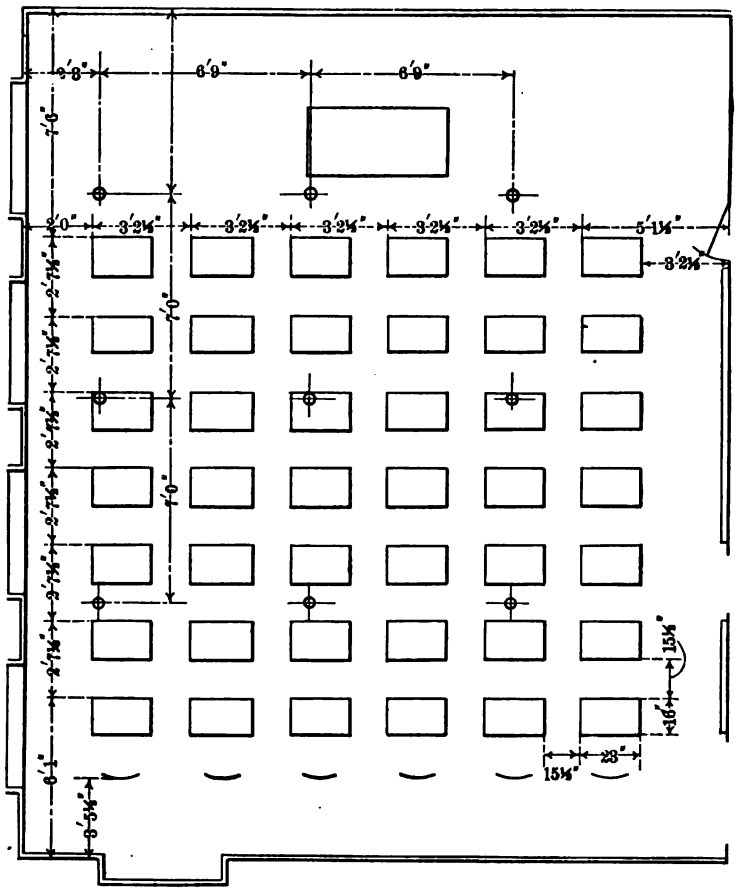


Fig. 140.

fixture being used. The reflector was of prismatic glass with a diffusing enameled coating, and the lamp, which had a frosted tip, was located so far within the shade as to keep the light effectively out of the pupils' eyes.

The unsymmetrical positions chosen for the outlets were found to be very efficacious in avoiding head and hand shadows, which

were at no point troublesome. The position of the lights is shifted slightly forward to avoid the head shadows and slightly to the left to avoid the hand shadows. The illumination thus attained was very uniform, being approximately 2.5 foot-candles at every desk, which amount was found to be fully adequate for ordinary schoolroom purposes. Approximately this scheme of illumination is being installed in all the new schoolhouses in the city of Boston, and the older ones are being changed to accord with them.

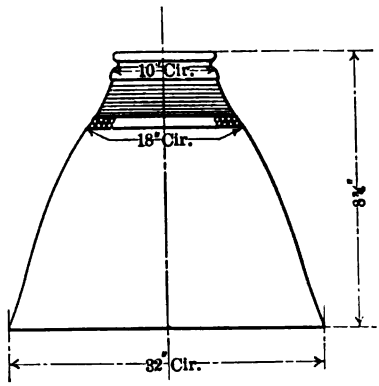


Fig. 141.

This system superseded a semi-indirect system in which six clusters symmetrically placed, each of four lamps, were inclosed in shallow opal bowls pointed upward to secure diffusion from the ceiling and covered with plate glass to keep out dust. This system, although taking the same energy as the one later adopted, gave only 1.5 foot-candles as against 2.5, showing, therefore, about the usual ratio between direct and indirect lighting. With 60-watt tungsten lamps instead of 40-watt, the illumination is raised to about 3.75 foot-candles, which is a somewhat better figure in cases where much work by artificial light has to be done. It was deemed desirable to meet the trying period at which natural light has to be abandoned and artificial light used, by making the passage from one to the other complete by drawing the window shades as soon as artificial light became at all necessary.

It is interesting to compare this result with that reached by Dr. Harman, the oculist of the London County Council Education Department and reported in "The Illuminating Engineer" (London). Fig. 142 shows his arrangement of lights in a typical schoolroom to accommodate forty pupils at twenty double desks. An asymmetrical arrangement very similar to that found by the Boston Commission is the result of his investigation, either four or six units being employed. A special light with opaque reflector is placed at the position marked X at the left of the master's desk, to be used either for the desk or the blackboard, as required.

The shades recommended are deep enough to shield the children's eyes and whether for gas or electric lighting the arrangement shown is a suitable one, although necessarily somewhat less uniform in its results than the Boston plan with its larger number of units. The lighting found on the desks in the better class of English schools is found to be in general terms 2 to 4 foot-candles, which appears to be a fully adequate amount. In the London Arts and Crafts School, the illumination is carried, as it should be, considerably higher, ranging from 4.5 to 8 foot-candles and reaching a perhaps unnecessary maximum of 30 foot-candles in the wood-carving room, where localized pendent lighting is employed. These illustrations show clearly the general requirements in schoolroom lighting.

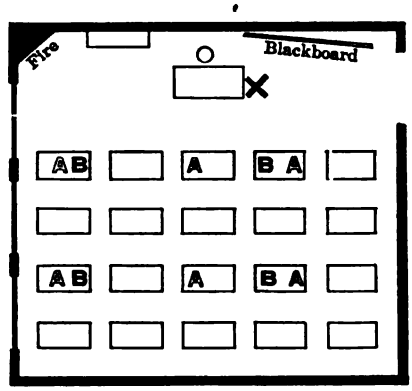


Fig. 142.

The lighting of the blackboards is a matter of special concern, and in arranging the lights particular care should be taken to see that there are no troublesome reflections from the blackboard for any point of view. The most effective precaution is to have the blackboard lighting well diffused, to avoid the use of shiny enameled surfaces on the blackboards, and to see that they are kept clean so as to secure proper contrast when the boards are in use. The blackboards of the Boston schools are upon the right-hand side of the room and adequately lighted from the lamps nearest them.

Lighting Tennis Courts. — It is only occasionally that a large and high interior has to be brought to a very high degree of illumination. Perhaps the most difficult task of this kind is the

artificial illumination of courts for lawn and court tennis. In these cases, particularly if a fast game is being played, the illumination must be both high and uniform, and the sources must be kept high to be out of the way of flying balls and to reduce the glare in the players' eyes.

The lawn-tennis court is the easier to light, since the walls do not come into play. At least 4 to 5 foot-candles is the illumination required, and more is better. The best results which the author has reached in his own practice have been with mercury arcs. In several instances a dirt court illuminated by 12 of the commercial tubes, each about 22 inches long, equally spaced in two rows, with their lengths crosswise the court, has given very satisfactory playing conditions. Fifteen such tubes placed in three rows would

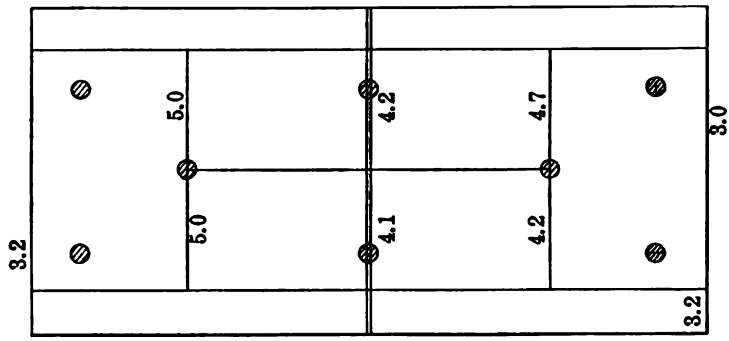


Fig. 143.

push the illumination a little higher and would be more satisfactory for a court much in use. The tubes are, of course, shielded by wire netting to avoid their being broken by flying balls. Their height in these cases is about 25 feet.

An interesting scheme has recently been successfully tried in London for this purpose, in which the interior of the building, except for the lines of the court and the top of the net, was made dead black to secure greater contrast between the balls and their surroundings. In this case, 8 nominal 1500 candle-power high-pressure inverted gas lamps were used, with reflectors above them and ground-glass screens below. These were arranged as shown in Fig. 143. The illumination obtained was 4 to 5 foot-candles and the installation served its purpose admirably The foot-candle readings obtained are shown on the plan. Yellow flame arcs simi-

larly placed would give excellent results, but they are somewhat more dazzling than the mercury tubes or the press-gas lamps.

The problem of lighting a court-tennis court is considerably more difficult. In one instance the author obtained a good result by using 18 double 22-inch mercury lamps, equally spaced in three rows over the court. The interior color was, of course, greatly changed when the artificial illumination went on, but the contrasts obtained were satisfactory and the installation has given good results. Whatever be the illuminant chosen, particular pains must be taken to get strong light in the extreme corners of the court and on the tambour.

Hand-ball and squash courts are easily illuminated on about the same basis as in lawn-tennis courts, but up to the present a racquet court defies all attempts at adequate artificial illumination. The balls are so small and the pace so terrific that no ordinary amount of light seems to produce any useful result. At the most modest estimate at least twice as much light is necessary as in court tennis, and it is doubtful whether even this would be enough for a really fast game.

The Lighting of Libraries and Similar Buildings. — Libraries and museums and similar public buildings demand a somewhat specialized illumination both with respect to intensity and distribution. In a library the first condition is that there should be in all parts of the building where general reading is to be done light sufficient for reading, easily and comfortably, at any seat in the room, any book which may be in use. Second, there must be complete absence of glare either from the luminous sources themselves, or indirectly from the paper of the books. Third, for the use of bookshelves or in rooms for general purposes, there must be a comfortable general illumination irrespective of the positions of the readers' seats.

The first requirement is a somewhat severe one, since lighting which, for example, is quite sufficient for a school desk will be found insufficient when reading books in fine type or studying critically maps and engravings. Among library authorities who have acquainted themselves with illuminating conditions, and among illuminating engineers who have worked on this problem, there is general agreement that illumination up to nearly 5 foot-candles is necessary at the reading tables. For general use about the room 1 or at most 2 foot-candles is a liberal allowance.

The natural inference from these requirements as to intensity is that the best system for illuminating the reading rooms of a library is a combination of a general illumination with localized lights on the reading tables. This is certainly the most economical solution of the problem and perhaps the most generally applicable. For this purpose well-shaded lights near the ceiling may be utilized to produce 1 to 2 foot-candles over the whole working area. On the reading tables lamps carrying the sources of local illumination should be placed, so shaded as to keep the light out of the readers' eyes, and to avoid as far as possible strong direct reflections from the paper.

The first part of the task, that is, general illumination, is a very easy and obvious matter. The second is not. In many libraries rather wide tables with fixed table lamps along the center line are used, and sometimes with extremely bad results. A fixed lamp on a wide table if at a sufficient height to spread the light the full width of the table is extremely likely to shine directly into the eyes of persons below the average height when seated, and to produce serious glare by direct reflection of the light from the book.

In one library with which the author had to deal, the glare produced in these ways was so serious as to make reading very uncomfortable, and the situation was far from being relieved by the use of unshaded, though frosted, incandescent lamps for general illumination.

The remedy applied was to place these lamps in diffusing balls and to substitute for the fixed standards movable student lamps with deep 10-inch porcelain shades, flashed with green on the outside, and containing 16-c.p. lamps, frosted, well up toward the top of the cone. The position of these shades was adjustable, and the lamps themselves, being on flexible cord, could be shifted to suit the requirements of the reader, so that ample light could be gained without glare from the lamp itself, and the position of the light could be so adjusted as to avoid direct reflection from the paper. In small libraries with relatively small reading tables and a limited number of readers, this is probably the best arrangement.

For reading rooms of large size having to accommodate many readers, movable lamps are somewhat troublesome, and if the table is not too wide fixed lamps along the center line, shaded somewhat as described and placed at a height to keep the light out of the eyes, can be made to do almost equally well. They should be so adjusted

that the reader when sitting at the table will naturally place his book far enough under the lamp to avoid specular reflection into the eyes. Lamps adjustable in height, if not in position, are highly desirable for such reading-room use. Nothing better than the green-flashed porcelain shade has yet been devised for a table lamp.

The distribution of light may sometimes be improved by placing a reflector within the shade directly over the lamp to widen the distribution, or sometimes by closing in the lower part of the shade with a ground-glass diffusing shield. The student lamp equipped with such a diffuser furnishes perhaps the very best form of illumination, where the use of movable lamps is permissible.

Where many bookcases are around the reading room, lamps in opaque reflectors, with their apertures facing the shelves, may be advantageously used for lighting the books. An excellent form of trough illuminator for doing this work is shown in Fig. 125. The illumination here may well be 2 or 3 foot-candles. Similar lamps with reflectors are desirable for aiding the inspection of card catalogues. In this case the illumination should be pushed somewhat higher, perhaps quite as high as at the tables, since the entries are not always clearly legible.

In some instances very excellent results have been reached in reading rooms by general illumination only, sometimes in the form of wholly indirect lighting. Considering the area to be lighted and the usual height of such rooms, however, this method, while it may be made beautifully effective, is always wasteful of energy.

A library stack can be very well lighted by the use of reflectors as just shown, and this is much superior to the common arrangement of bare lamps upon cords hung in the spaces between the shelves and turned on by anyone searching for books. The lights in each bay of a stack should be controlled by a switch at the entrance.

Delivery rooms and similar public rooms are best treated by general illumination to the extent of 2 or 3 foot-candles, the exact form depending on the use to which the room is to be put. In case such public rooms contain any special features to be illuminated, the plan of lighting must be subordinated to these particular things. Here, even more than elsewhere, the installation of light sources must be considered as only a means to an end. Perhaps the very worst installation of lights in a library yet recorded was the original one in the delivery room of the Boston Public Library,

a room enriched by the beautiful mural paintings of Abbey. This unique example of inappropriate lighting is shown in Fig. 144. The chandeliers were offensively obtrusive at best, and they were so located as to conceal the mural paintings by their glare instead of illuminating them so that they could be seen. The picture here shown was, of course, taken by daylight. By night the effect was almost indescribably bad. Fortunately this installation was soon thrown out and replaced by the effective and unobtrusive trough lighting system of Fig. 145, so inconspicuous as to be scarcely



Fig. 144.

noticeable in the cut, yet fully effective in revealing the beauty of the pictures.

Perhaps the most troublesome portions of a library properly to illuminate are the newspaper and periodical rooms, where the reading matter is kept on slanting racks. With the lights as commonly placed above these, there is almost a certainty of direct reflection from the paper into the eyes. Trough reflectors with diffusing screens may be used with advantage, and here, if anywhere, the indirect system of lighting by the diffusion of the ceiling and walls finds its best application. It requires a considerable amount of energy to carry out the indirect lighting scheme in such

a room, probably in the neighborhood of 1 candle power per square foot, but when properly done it averts completely the reflected glare from the paper while giving ample reading illumination.

Museums and similar structures, like libraries, require somewhat specialized lighting, the main point being to illuminate the cases containing the objects on view to a fairly high intensity without producing disagreeable reflections from the glass surfaces and without placing lights where they will shine in the eyes of the visitors. Here again there is much to be said for indirect lighting, from sur-



Fig. 145.

faces high enough to be out of the direct line of vision, and spacious enough to give very low intrinsic brilliancies. Certain cases will probably be found to require extremely brilliant lighting — more brilliant than they can economically receive from indirect sources. For such instances the familiar devices used in showcases are well adapted. These combined with a general indirect illumination probably furnish the best solution of the museum problems.

In very large interiors without high galleries, arc lighting may be very effectively used, provided the arcs are well shaded. It is wise to group them so that no single arc shall entirely dominate the illumination at any particular point. It is better to lose a

little in uniformity of the total illumination throughout the area than to take the chances of flickering, which is not entirely suppressed even in the best arc lamps.

In a big space arcs can be treated much like incandescents in a small space, but the detail of the work varies so much that only very general suggestions can be given. Often temporary illumination has to be undertaken, and must be fitted to the case in hand. One of the most beautiful examples of such work that ever fell under the author's notice was the illumination of Madison Square Garden for a chrysanthemum and orchid show some years since. The feature of this work was the very extensive use of both arc and incandescent lamps inclosed in Chinese lanterns. The huge lanterns containing the arcs were very striking, and the whole effect was most harmonious, while the illumination was thoroughly good. It is mentioned here merely as a clever bit of temporary lighting treated to suit the particular occasion.

In this lighting of large interiors the smaller arcs worked on constant-potential circuits are very useful, although not very efficient. Those taking 5 to 6 amperes give excellent service, and fair results can be obtained with lamps working down even to 4 amperes. Such arcs are equivalent to from 10 to 15 16-c.p. lamps in practical effect, and give a greater candle power per watt. The "intensified" arcs are by all means the best for such work.

Incandescent lamps of the Nernst type or the largest sizes of tungsten lamps may be utilized in a similar way, in forming a good basis of illumination where the total amount of light is considerable. In other words, when one is dealing with very large inclosed spaces, the lighting is simplified and made more efficient by utilizing the more powerful radiants.

In certain cases, particularly railway stations and other buildings likely to be rather smoky, arcs have to be the main reliance, since the globes of incandescents grow dim so quickly that cleaning them is an almost interminable job. Hence it is best to use comparatively few powerful radiants. The arcs should be carried rather high, at least 20 to 25 feet above the ground or floor. Assuming 0.5 foot-candle as the minimum, and taking into account the illumination due to adjacent lamps, each arc can be counted on to illuminate over a distance at which it gives 0.25 foot-candle. For close detail reference must be made to the actual

illumination curves of the type of lamp used, and the general problem is analogous to street lighting.

All arcs in inclosed places should have at least one opal globe, and when used where, as in railway stations, diffuse reflection is of small amount, should be provided with reflectors to utilize the light that would otherwise be wasted.

Certain classes of interiors require, on account of the uses to which they are put, especial adaptations of the radiants, either in kind, amount, or position. One of the commonest demands is for an illumination of unusual brilliancy and steadiness in situations like draughting rooms, and shops where fine work is done, where the eyes are under steady, if not severe, strain. Ordinary good reading illumination, such as we have been considering, must be considerably strengthened to meet these requirements. Simple increase in the number or power of the radiants sometimes meets the conditions, if such increase can be had without thrusting too powerful lights into the field of vision.

It may be necessary to furnish 1 candle power for each 2 square feet of area, or, in extreme cases, 1 candle power per square foot. One of the most useful schemes for supplying such large amounts of light is the use of the inverted arc in connection with a very light interior finish.

The ordinary continuous-current arc, in virtue of the brilliant crater of the positive carbon, throws its light downward; but if the current be reversed so as to form the bright crater on the lower carbon, most of the light is thrown upward toward the ceiling, and is there diffused. If, as usual, these arcs are arranged with inverted conical reflectors of enameled steel or the like, all the direct rays are cut off and the entire illumination is by the diffused rays. The result is a very soft and uniform light, white in color, and of any required brilliancy. Fig. 146 shows in diagram the principle of this device. In case a white ceiling is not available, large white diffusing screens over the lamps, of enameled metal or even of tightly stretched white cloth or paper, answer the purpose. Indeed, this was the original form of the device as shown by Jaspar at the Paris Exposition of 1881.

With reference to Fig. 146, it is sufficient to note that the conical reflector should be rather shallow, just deep enough to throw the light wholly on the ceiling and upper walls, but shallow enough for two neighboring lights, as shown, to distribute light

over each other's fields, which improves the average steadiness of the illumination. The arcs need no diffusing globes, a clear globe being sufficient, and open arcs may be freely used, to the material improvement of the luminous efficiency, never very high in this form of lighting.

The heights of the arcs should depend somewhat on circumstances regarding the appearance and the purpose of the lights, but will generally be half to three-fourths the height of the room. The reflectors may be from 3 feet to 6 feet in diameter, and may have an angle at the apex of 120 degrees to 140 degrees. Only in case of having to throw the light on special screens rather than on

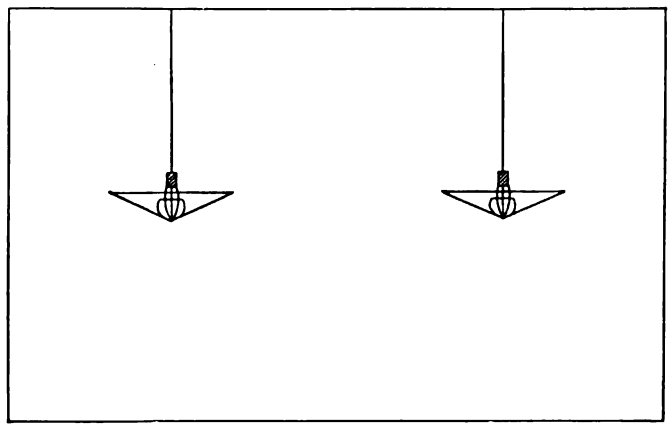


Fig. 146. — Lighting by Inverted Arcs.

the natural ceiling should the reflectors have less aperture than just indicated. They then become of the nature of projectors, and the angle at the apex may be 90 degrees or so.

As to the efficiency of such illumination, one may roughly assume 1 watt per spherical candle power for powerful open continuous-current arcs, and may reckon on a loss of about one-half in the process of diffuse reflection. The diffuse illumination may then be taken as being in candle power about 0.5 the number of watts expended, not including artificial resistance. Thus, a continuous-current arc, taking 9 to 10 amperes at about 50 volts, utilized in this manner, will illuminate 250 square feet to 300 square feet on the basis of 1 square foot per candle power, or 500 square feet to 600 square feet at 2 square feet per candle power.

It must be noted that if ordinary inclosed arcs are used in this way, materially less light is obtained, as is well known. Even with both outer and inner globes clear, one cannot count on much better than 2 watts per mean spherical candle power. Alternating lamps require, of course, still more energy, and with inclosed arcs in general one would hardly find it advisable to allow, when using ceiling diffusion, more than half to three-fifths of the area per watt just indicated for open arcs. Inclosed arcs have no crater, which operates greatly against their effectiveness in this class of lighting.

These figures are necessarily only approximate, but while inclosed arcs have some conspicuous virtues, high efficiency as respects mean spherical candle power is not one of them. In all this lighting by diffusion the diffusing surfaces *must* be kept clean, else there will be much loss of light. Under even the best conditions, one does not do very much better than 2 watts per candle power, and lack of care or bad engineering may easily transform this into 3 or 4 watts per candle power, which is no better efficiency than incandescents would give. In point of efficiency the larger sizes of tungsten lamps are better than inclosed arcs for such work.

The chief advantage of this diffused lighting is that it enables one to secure very brilliant illumination with white light, without trying the eyes with intense radiants.

Such illumination has, however, one curious failing, in that as ordinarily installed it is *shadowless*, and the light has no determinate direction. For certain kinds of work this is a very trying peculiarity, severely felt by the eyes. It may be remedied in various ways, of which perhaps the simplest is the lateral displacement of the lamps shown in Fig. 147.

This gives a predominant direction to the light, something akin to the effect produced by a row of windows along the side of the room, and is probably as near an approach to artificial daylight as can be attained by simple means.

In using the arrangement of Fig. 147, about the same relative number of arcs is required as in Fig. 146, but they are placed in one row instead of two. The unilateral effect could be greatly enhanced by a diffusive screen *ab*, Fig. 147, running along back of the arcs. Its angle with the ceiling evidently should depend on the shape of the room.

Unilateral illumination, whether diffused or not, is often desirable from a hygienic standpoint. In many cases well-shaded arcs may

replace the diffused lighting just described, though such direct lighting is generally rather less steady. But it must be remembered that an arc having both inner and outer globes opalescent is scarcely, if at all, more efficient than incandescent lamps, assuming both to be worked off constant-potential mains; hence, unless the whiteness of the arc light is essential, incandescents, being steadier, are generally preferable.

In factories where colored fabrics are woven, and in shops where they are sold, white illumination is a matter of great importance, and arcs are especially useful. In the mills the necessary illumination depends largely on the color of the fabrics. It should, as

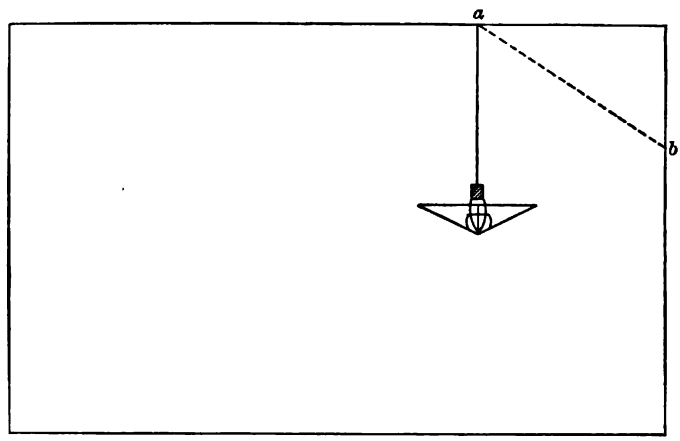


Fig. 147. — Unilateral Illumination.

a matter of experience, range from 2 square feet per candle power to 1 square foot per candle power in passing from white to dark and fine goods. The candle power noted here is the mean spherical, or hemispherical, if reflectors are used, taken from the real performance of the arc well shaded. This qualification means practically 300 square feet to 400 square feet for each arc of 450 watts to 500 watts in the extreme case, and 600 square feet to 800 square feet for white and light-colored goods. Shops where such goods must be sold by artificial light should be lighted on very nearly the same basis. For brilliant illumination, where color distinctions must be accurately preserved, the arc at the present time stands preëminent, and should generally be used. It must

be remembered, however, that inclosed arcs are distinctly bluish unless the current is pushed up nearly to the limit of endurance of the inner globes, and hence, when used in situations where color is important, should have shades tinted to correct this trouble. The common opalescent inner globe is entirely insufficient for the purpose. The "intensive" arcs are best suited to the purpose.

Where arc lights are not available, and it is desired to furnish approximately white light, there is difficulty in meeting the requirement. Mantle gas burners, with extreme care in selecting tinted shades to correct the color of the light, may be made to give fair results, but are considerably inferior to arc lights.

It should not be forgotten that good illumination in a workshop tends materially to increase the quantity and improve the quality of the work turned out.

In most instances the color of the light within the range of ordinary illuminants is not a matter of considerable importance, but the light must always be reasonably steady. Hence the incandescent lamp and the mantle burner for gas are by far the most valuable sources of light commonly applicable. Ordinary batwing gas burners are probably the worst in point of steadiness, although a badly adjusted electric arc is a close second.

Where very powerful radiants are desired, the large regenerative gas burners give a very brilliant and steady light. They throw out, however, a great deal of heat, which is sometimes objectionable, and are less economical of gas than the mantle burner. The modern "press-gas" lamps with inverted mantles are still better.

A very special branch of illumination is the lighting of immense inclosed spaces, such as are found in exposition buildings. This work is on such a large scale that it almost partakes of the nature of outdoor lighting, with which it is very intimately connected as a practical problem. The amount of light required in single inclosed spaces of colossal dimensions, like exposition halls, varies considerably according to the practical use to which the space is to be put. As a rule, the most brilliant and useful illumination in these large spaces is secured by the use of arc lights to the exclusion of other illuminants. In a building covering one or several acres, and perhaps 100 feet or more in height, incandescents of ordinary powers look lost; and if the roof is not to fade away into darkness, a very large number of lights must be required to bring

it into prominence, placed so high from the floor as to be of little service for the general illumination.

Moreover, such buildings have generally a large amount of glazed side and roof space, furnishing the ordinary daylight illumination. Consequently the walls and ceiling diffuse very little light. With arc lights the power of the individual radiants bears some respectable proportion to the size of the space to be illuminated. The luminous efficiency is increased, and, by sufficient massing of lights with reflectors, even the highest halls can be admirably lighted. The work can, of course, be beautifully done with incandescents if enough are available, but at considerably lessened economy.

The amount of light required per square foot of floor space is very considerable, owing to the height and bad diffusing properties of the building, and for the best results 1 actual candle power should be furnished for each 2 square feet to 3 square feet, according to conditions.

Incandescent lamps have a very high decorative value in connection with such work, but to be used effectively must be massed somewhere near the plane of illumination, lights in and about the roof being practically only for decorative purposes. Used in sufficient numbers, however, they give, in virtue of their complete subdivision of the illumination, a better artistic result than can be obtained with arcs.

The subject of exposition illumination is so large and so special in its character as to be hardly appropriate to the scope of the present work.

CHAPTER XII.

EXTERIOR ILLUMINATION.

By exterior illumination is here meant that which is applied outside the confining walls of buildings. Interior illumination, which is circumscribed by such walls, is powerfully modified by their particular characteristics as to color, texture, and coefficient of reflection. Of the six surfaces which bound a typical interior space, four or five are generally moderately good reflectors, or at least are not so low in reflectivity as to be at all negligible. One, commonly the floor, is often nearly or quite negligible, and sometimes, in the case of high vaulted ceilings, another bounding surface may be left for the most part out of account. In exterior lighting the case is radically different. In some instances there are no bounding surfaces to the space illuminated of such character or at such distances as to afford any secondary illumination worth mentioning. In other cases there may be two or three reflecting surfaces, generally rather bad, to be considered, but in all cases the upper limiting surface is absent and the condition generally approximates the illumination of an indefinitely extended room with a poorly reflecting floor and an absolutely black ceiling.

One, therefore, deals, in exterior lighting, chiefly with light received directly from the radiants, and in so far the case is theoretically simpler than interior lighting. On the other hand, the lower bounding surface in exterior lighting may be relatively important, particularly in certain cases of low illumination to be described later on. Now and then there are lateral bounding surfaces which are not negligible, and there are also extraneous sources of light which in practical illumination are of great importance, but, on the whole, exterior illumination depends for its effective magnitude upon light received directly from the radiants in use.

From the economic standpoint exterior illumination presents a favorable case, inasmuch as relatively low intensities are employed, since space out-of-doors does not need to be lighted to the degree required for occupations or amusements customarily carried on indoors. Broadly, then, the art of exterior illumination deals gen-

erally with the distribution, directly from one or more radiants, of a moderate degree of illumination without much effective aid from any secondary sources of light.

Most generally, illumination out-of-doors is applied to a single surface, the ground; but there are cases in which the fundamental requirement is the lighting of vertical surfaces, such as are presented by buildings. It is this class of lighting which, perhaps, bears the greatest resemblance to the conditions of interior lighting and which will be considered in the next chapter.

The main class, therefore, of exterior illumination here to be considered, and the one of the greatest economic importance, is that of street lighting, in which the distribution has to be chiefly lengthwise of the streets. Bounding surfaces in the form of buildings may or may not be of material importance, and the intensity required is rather moderate. It is lighting in one dimension, rather than in two, as in the case of public places and parks, or in three, as in the case of interiors. Prior to discussing this, however, it will be well to consider the somewhat more general problem of place and park lighting.

The lighting of public places and parks differs from street lighting in that the areas to be illuminated are not narrow strips like a street, but extend in both directions, and in the case of public squares the lighting of the adjacent buildings is a thing not to be left out of account. The purposes of these kinds of lighting differ very widely. Public squares are illuminated with special reference to the convenience and pleasure of the people who use them, often in great numbers. Such places are frequently dense centers of traffic along the streets that meet upon them, are generally located in the more thickly populated parts of the city, and are often scenes of great activity during at least the earlier hours of the evening. Man has become steadily more and more a nocturnal animal, and it is in these public squares that provision must be made for his habits. Both his protection and his convenience are objects which must be borne in mind when designing the illumination. The police value of lighting has long been recognized, and emphasis was laid on it in an interview recently by the Chief of Police in Paris, who pleaded for adequate all-night lighting as an adjunct for the preservation of order. In considering public squares, the value of ample light as preventive of crime is very considerable, but perhaps less important than it is in some of the streets. A public square is

not a spot generally chosen for "holdups" or other extreme crimes of violence. It is, however, a location where the pickpocket and petty thief may ply their vocations, and for full protection against these gentry good illumination is needed.

Fundamentally, the lighting of a public square is for the convenience of the passersby. They not only wish to walk without tripping over obstacles, or drive without plunging into open manholes, but they wish to meet and recognize their friends without bumping into them, to glance at a railway time-table, to read the address on a letter or the number on a house, and, in general, to see as comfortably and get about with as little thought of inconvenience from lack of light as would be the case toward the end of a winter afternoon. In other words, the peculiar requirements of convenience demand that public squares which are largely used should be liberally lighted—as well lighted as the best-lighted streets, much better lighted than the ordinary streets. It is consequently necessary that they should be lighted with some approach to uniformity, otherwise there will be dark spots not only unpleasant in effect but inconvenient for the man on the street. From a practical standpoint such requirements can be met thoroughly well in only one way,—by the use of a very large flux of light from sources placed high enough to be out of the immediate field of view. This is akin to the ordinary requirements of interior lighting, in that one should be able to see easily and comfortably without brilliant sources of light intruding themselves in the direct line of vision.

The lights ordinarily used for street lighting, if sufficiently numerous to give the requisite volume of illumination in a public square, are certain to interfere with vision by their brilliancy and position near the line of sight. The author calls to mind three famous places which serve as examples of the bad and good methods of place lighting. One of these is the Place de la Concorde, Paris, lighted with innumerable small units placed on short posts that stand in serried ranks all about the famous spot. The lighting of the pavement is moderately bright, but the effect is distinctly unpleasant and inadequate; petty from the great number of lamps and the obtrusiveness of their supports. The second is Trafalgar Square, London, lighted with arcs to a somewhat higher degree than the Place de la Concorde, but yet missing something of distinguished beauty or notable excellence in the results. It is a fairly well-lighted square, which could be made much better

were the lamps placed farther out of the field of view and the total volume of illumination considerably increased. Finally, as an example of the very best that has been done in such lighting, one may mention the western approach to the Brandenburger Thor in Berlin, which is brilliantly and beautifully lighted by two groups of enormously powerful lamps placed more than 20 meters high on columns which are works of art by day as well as by night. Fig. 148 shows the daylight aspect of the place. The actual illumination on the pavement, while amply brilliant, is



Fig. 148.

probably no higher than is reached in Copley Square, Boston, or in any one of several public places in other American cities.

The design of the illumination in a public square is not a simple matter. First, considering the amount of light required in order to meet the requirements of being able to read notes, time-tables, and addresses comfortably, as well as to recognize persons quickly and easily, the illumination must be pushed far beyond that found in most American streets unless almost under the lamps. To meet these requirements the average value of the effective illumination should be not less than 1 meter-candle and the minimum should be at least 0.5 meter-candle. Anything less than this is insufficient for the purposes mentioned, and more is preferable.

One can form a cursory idea what this intensity means by realizing that full moonlight is in our latitude on a clear night about 0.3 meter-candle, a degree of illumination that reduces visual acuity to about 0.25 or 0.30, as shown by actual experiment in moonlight, and reduces shade perception in a similar degree. Both the loss of acuity and the increase of Fechner's fraction below 1 meter-candle are very rapid, and at these low illuminations the eye is peculiarly susceptible to the effect of bright lights within the field.

The term "effective illumination" is used advisedly, with full knowledge of the fact that there is some discussion as to what constitutes effective illumination for the purpose of lighting such

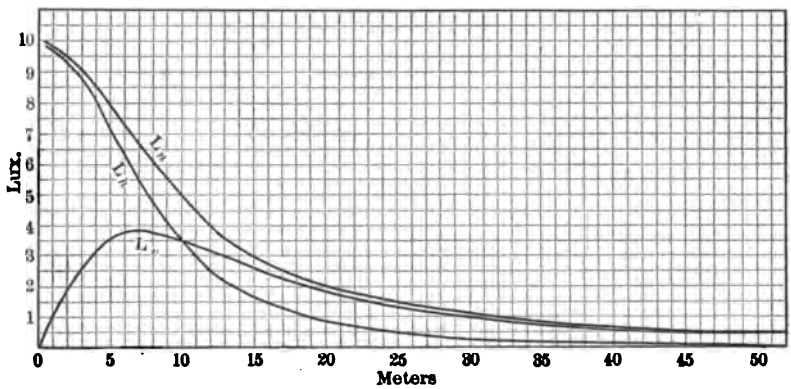


Fig. 149.

a space as we are considering. While the illumination on a surface normal to a ray from a radiant of known power follows simply the inverse-square law, if the ray does not fall normally upon the surface the intensity is reduced in proportion to the cosine of the angle of incidence for a horizontal surface, and in proportion to the sine of the same angle for a vertical surface. Consequently, if one attempts to reckon the illumination to be received at a particular point in a public square, he finds himself in a quandary as to whether he shall reckon the illumination as on a normal plane, the illumination resolved on a horizontal plane, or resolved on a vertical plane, the three hypotheses leading to three radically different results as to the value of the illumination. The curves of Fig. 149 give the three values of the illumination

obtained on these three hypotheses from a source of 1000 uniform spherical candle power placed at a height of 10 meters. Which of these divergent values should be reckoned as the correct one for the purpose of designing illumination? The question is an intricate one on account of the varying purposes for which one requires light in such a situation.

Here, again, the similarity to interior lighting becomes evident, since the case corresponds quite closely to that of a room lighted from several sources. The solution is, in the author's judgment, indeterminate, since there are more unknown and perhaps unknowable quantities than definite data which can be applied to them. One can, however, arrive at a common-sense approximate solution by establishing this criterion, — that the light shall be such as to meet the severest practical test among the various requirements of its use; that is, the reading test. For this one can always readily take advantage of normal illumination, and one customarily does so. This requirement means, therefore, that the normal illumination received from the nearest light shall at no point fall below 0.5 meter-candle, and shall, as a whole, equal or exceed 1 meter-candle. With this quantity of illumination all practical requirements other than reading are met very easily.

The problem of design, then, resolves itself into a comparatively simple construction, — the placing of radiant sources so that if one draws about each of them a circle at such distance that the normal illumination received from the source at that circle shall be 0.5 meter-candle, these circles shall overlap so as to fully cover the area concerned. The subsequent design consists in so planning the distribution from each source that its effective radius of action shall be as great as possible. With all practical illuminants the illumination, if sufficient at the periphery of the circle, will be sufficient for all points within.

For the purpose in hand, the fundamental equation connecting the various quantities is

$$L_n = \frac{I}{l^2} \cos^2 \alpha, \qquad (1)$$

where L_n is the illumination, l the height of the radiant above the plane of reference, I the intensity, and α the angle of incidence, which is equal to the angle between the ray and the lamp-post. Of these quantities in actual computation any one may be assumed on the conditions, or any one may be required to be found. I and

the angle α are dependent variables, and in practice are taken from the distribution curve of the radiant. This being known, the required height of the lamp to produce a given illumination, L_n, can be obtained from the transformed equation,

$$l^2 = \frac{I \cos^2 \alpha}{L_n}. \tag{2}$$

For instance, taking L_n at 0.5 meter-candle and I for the angle of incidence 70 degrees, as 2000 candle power, l comes out at about 22 meters; and it will be generally found that with distributions common for powerful illuminants the heights, for illumination of the order of magnitude here required, come out rather large, higher than it is generally convenient to place the lamps.

Again, the height of the lamp being chosen at some easily practicable figure and the curve being known, the angle of incidence corresponding to the required illumination is given by the transformed equation,

$$\cos^2 \alpha = \frac{L_n l^2}{I}. \tag{3}$$

Whether the angle of incidence is assumed, or thus reckoned, the radius of the circle for the required illumination at the periphery is

$$r = l \tan \alpha. \tag{4}$$

Since α and I are mutually interdependent, the solutions thus obtained are not exact; but having the distribution curve of the lamp, a slide rule, and a table of natural trigonometrical functions, one can get at the facts in the case in very short order. As an example in the application of these formulæ, the following data derived from the illumination of Copley Square, Boston, which is lighted by four very powerful flaming arcs, may be instructive. Here l equals 16 meters and I is very conservatively taken at 2000 for angles in the vicinity of those dealt with. Fig. 150 shows the curve of the lamp with opal globe. Applying equations 3 and 4 for L_n equals 1 meter-candle and 0.5 meter-candle, respectively; r equals 41.6 meters for 1 meter-candle and 62.5 meters for 0.5 meter-candle, approximately. Fig. 151 shows these circles as laid down on a map of the Square. It will be seen that the 1-meter-candle circles overlap liberally, and the 0.5-meter-candle circles almost touch the adjacent lamps. It was considered desirable here, especially on account of the fine neighboring buildings and the large traffic through the streets, to

carry the illumination high, and the 0.5-meter-candle circles reach well out into the adjacent streets. The great overlap of the circles of illumination renders the lighting extremely uniform, and one can

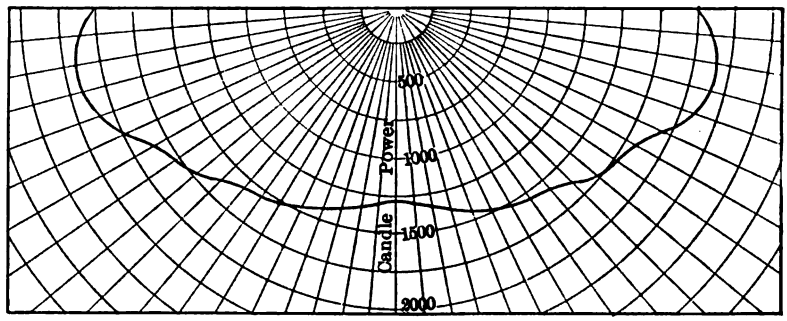


Fig. 150.

read a newspaper anywhere in the Square without any sensation of glaring brilliancy being perceptible, owing to the great height of the lamps. Ordinarily the 0.5-meter-candle circles in place lighting

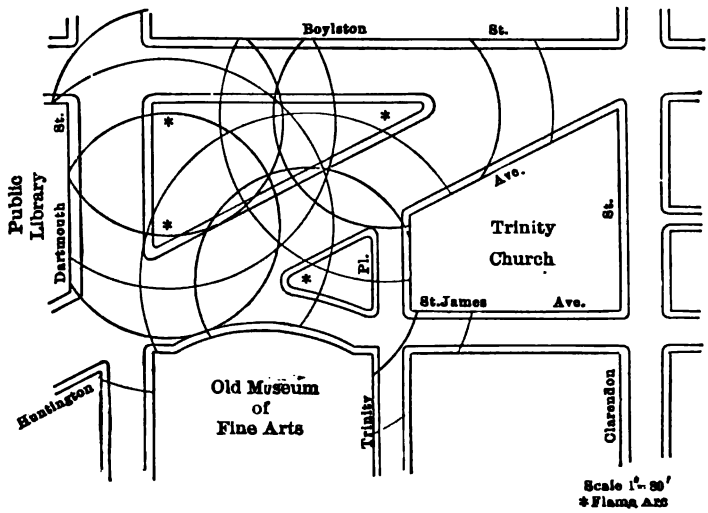


Fig. 151.

would overlap about as much as the 1-meter-candle circles do in this instance. Had it been feasible to use poles fully 20 meters in height, a slightly different reflector could have been advantageously



Fig. 152.

employed on the lamps with the probable result of increasing the efficiency of the lighting very materially. But the lamps being on series circuits, on which the use of iron poles is not permitted in Massachusetts, it was not practicable to go higher. Fig. 152 shows the night view of Copley Square thus illuminated. Applications of the principle of design here suggested are independent of the power or character of the radiants and will serve for the lighting of public places of any size or importance to any degree of



Fig. 153.

brilliancy. In places of modest area a single central fixture bearing a group of powerful lights, or even a single lamp of high power, may yield admirable results. Fig. 153 shows an excellent example of such practice in the Alt-markt at Dresden, where the central feature is the great ornamental post bearing its cluster of six flaming arcs.

The lighting of parks differs somewhat radically from that of other public places for the simple reason that most parks are so little used after nightfall, except in very limited portions, that any

considerable degree of illumination is unnecessary. Now and then one finds a park which is used freely in the evening, and in such cases lighting on a liberal scale ought to be supplied, rising, rarely, to that appropriate for other public places. Generally speaking, however, the purpose of park lighting is purely the preservation of order and the marking of what are, so to speak, thoroughfares through the park.

From the police standpoint, which is the important one in park lighting, the requirement is for moderate illumination without dark spots in which the disorderly can lurk. Hence, as a rule, powerful radiants which, unless brilliant illumination is attempted, would be widely spaced and would tend to cause somewhat dense shadows ought always to be avoided in park lighting. Their only proper application to such work is where the illumination should approximate that of other public places, and in the case of large open spaces. Parks in general, therefore, require less light than any other class of public spaces which require illumination at all. In many instances, where parks are large and wooded, there can be no attempt at a general illumination even for police purposes, except in certain spots and along certain routes through the park. Where lighting is attempted at all, its intensity along the ways in the park should be the same as in a very moderately lighted street. On such ways it may fall still lower provided it is reasonably uniform,— as low, indeed, as average moonlight, perhaps 0.2 meter-candle or thereabouts. The objects to be seen by such lighting being nothing smaller than persons, the demand for visual acuity is small. Practically the problem amounts to furnishing enough light in a certain area to prevent unwarranted persons from lurking in the park after nightfall. Any light, therefore, by which the wandering policeman can make out a figure serves the purpose.

As a result of this police requirement the distribution of lights in a park has sometimes to be very singular, the lights being placed utterly irrespective of any systematic order, but where they will abolish dark spots under trees and behind shrubbery. For this purpose the lights are preferably of only moderate power, and should be placed low, where they can shine below the branches of trees. It is also important that lights so placed should be thoroughly screened so as to avoid glare. Under the conditions required the guardians of the peace can fulfill their functions most successfully when their eyes are adapted to a dim light, and dark

adaptation is spoiled by a very brief exposure to a powerful light or one of high intrinsic brilliancy. Even incandescent lamps, whether gas or electric, used for such park lighting as is here under consideration, should be put in ground glass or opal shades, preferably the latter, so that their light-giving power may be utilized without interfering with the vision of those looking toward them or passing near them.

The best results in park lighting in the writer's experience have been with 100-candle-power tungsten lamps in 12-inch diffusing balls, mounted about 10 feet above the ground, and in positions designated after conference with the police authorities. Larger units than these can rarely be utilized to advantage on account of their being too bright, and small ones similarly installed can frequently be made to serve the purpose. If similar lights are installed along the ways in the park which are desired to be lighted, they will do excellent service when so spaced as to give illumination similar to average moonlight, say 0.2 to 0.25 meter-candle. Where people congregate in the park the illumination should be carried higher, up to at least 0.5 meter-candle. In open spaces arcs can here be made to do good service, the illumination being planned exactly along the same lines as in the case of the public places already treated. Small units closely placed are less effective, except in lighting spaces like open-air restaurants, in which the lights should always be shielded by diffusing balls or shades. The minimum intensity of light in such places should be at least 0.5 meter-candle, enough to enable one to read a menu card or program. Park lighting, therefore, would seem to belong in a special class as regards intensity and distribution, and from its low intensity requires that particular pains should be taken to avoid glare.

Street lighting is in its origin and development essentially a police measure. Its history goes back to mediæval times, in which the streets, mostly unpaved and wholly undrained, were bad enough by day but worse by night. They were infested by thieves and highwaymen, cut-throats and drunken roisterers with rapiers ready for a quarrel. Paris, in particular, in which we have the first records of street lighting, was the scene of constant brigandage and crime from almost the earliest days of which we have record. Early in the fifteenth century, under Louis XI, flambeaux were ordered at the street corners, and lanterns in the householders' windows to coöperate with the night watch in promoting public

safety. Over and over again for the next two centuries and a half such ordinances were reiterated, always openly on the score of public safety from crimes of violence. In 1558 lanterns were ordered, at the corners of streets and at other suitable places, to be kept burning from 10 o'clock in the evening till 4 o'clock in the morning through the winter months. By these dim and flickering lights the course of the streets was at least marked, but they afforded scanty protection against marauders, and those who could afford it went accompanied by a retinue of torch bearers and an armed guard when traversing the streets at night. It was not until more than a century later that anything approaching public lighting was seriously attempted. In 1662 the first public lighting concern was given a franchise under a royal edict of October 14. This was a private enterprise of the Abbé Laudati, and its chief feature was the constitution of a corps of public lantern bearers carrying lanterns or flambeaux of a specified size and bearing as insignia the arms of the city. These were stationed at fixed posts along the streets and for a small fee would escort the nocturnal wanderer more or less safely on his way. Systematic street lighting was inaugurated about five years later, and the effect on public order seems to have been immediate, for at least two medals were struck within the decade, celebrating the institution of public lighting.

London was still worse off and save for the transitory effect of ordinances requiring householders to hang out lanterns the streets were unlighted and almost as full of danger as those across the Channel. It is worth noting that about this period some ignoble soul, whose name has very properly perished in oblivion, devised the original moonlight schedule as a measure of poor and pitiful saving. It was tried first, probably, in Paris, where it was railed against as "candle-end economy." London copied from Paris, and had made little progress before the end of the seventeenth century. At this period, however, the chief streets of Paris were systematically lighted by lanterns swung across the street, still the most efficient position for street lights. They were placed at about 20 paces apart and hung some 20 feet above the ground or pavement, as the case might be. Fig. 154 shows a nearly contemporaneous view of such suspensions. It was well into the eighteenth century before street lighting at public expense was customary even in the capitals of Europe. The subsequent 200 years have seen an

immense change in methods and material, but the purpose of street lighting has remained the same, and it is now, as it was four centuries since, a measure of public safety and an adjunct to the police force.

For practical purposes the street lighting of the seventeenth and eighteenth centuries was altogether insufficient and ineffective, but despite this it was found, as it is found to-day, a great preventive of crime. As the use of the streets by night has increased the necessity for lighting has grown with it. Lighting to-day bears a closer relation to public safety than it did when the only occupants of the streets after nightfall were a few crawling carriages

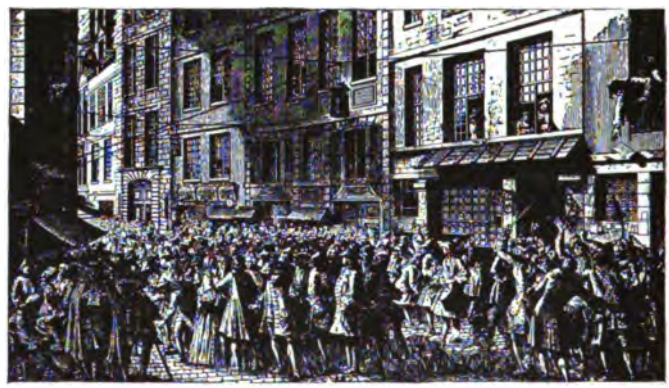


Fig. 154.

and a few belated pedestrians. It is necessary not only to light the streets well enough to mark their course and serve for the assistance of the guardians of the peace, but well enough to distinguish the way clearly, to avoid obstacles even when going at fairly high speed, to distinguish and recognize persons, and to tell where they are and what they are doing. The police should be able to note the actions of suspicious characters before they stumble over them, or to detect the number of a law-breaking automobile before it has vanished into the distance. All these requirements of a complicated civilization demand lighting upon a vastly more liberal scale than sufficed for earlier days, or than is found in many localities even now. It is pertinent, then, to inquire into the conditions of visibility that are present with artificial light in

the streets, and to find their bearing upon the intensity of light required.

Except in the vision of details at comparatively short range, we see things in virtue of their differences of color and of luminosity. In weak light color as such is inconspicuous, so that practical vision depends chiefly upon the power of distinguishing differences of luminosity. So far as the problems of artificial illumination are concerned, objects do not range over a wide scale of luminosity. Whatever may be the absolute values of light received, the relative values as expressed by the coefficient of reflection range practically from about 0.8 to 0.01, or a little less. In other words, the blackest object returns about one-eightieth the light returned by the brightest object. Ability to distinguish between stationary objects by their difference in luminosity depends, then, on the capacity of the eye as regards shade perception. The fundamental fact underlying this is that the eye can perceive within a wide range of absolute intensity a fairly constant fractional difference in luminosity. In bright light it ranges, say, from 2 to 0.5 per cent, with modest variations under special circumstances both ways from these values, which hold measurably well for values of the illumination from about 10 meter-candles up. As the illumination falls below this point there is a material increase in Fechner's fraction under ordinary circumstances, and we see less well, so that by the time the illumination is down to 1 meter-candle our shade perception is very seriously impaired, as is also our ability to distinguish details,— visual acuity. It should be mentioned that the loss of shade perception at low illuminations is very powerfully influenced by the state of adaptation of the eye with respect to light or darkness. With the eye well adapted to the dark, fairly good shade perception can be carried to illuminations very much lower than ordinary. In fact at 1 meter-candle or a few tenths the value of Fechner's fraction is influenced very much more by the state of the eye as regards dark adaptation than by anything else, so that when one is seeing fairly under a very low illumination, anything which tends to spoil the dark adaptation produces immediate blinding with respect to things otherwise easily seen. It is chiefly this fact which, from the standpoint of street illumination, renders glaring lights so troublesome.

Referring these things to the physiology of vision, the situation may be summarized by saying that below an illumination of

1 meter-candle, normal daylight vision, which is chiefly associated with the cones of the retina, is rapidly failing and throwing the burden of vision upon the rods.

There is, then, a physiological dividing line that can be drawn between illumination which permits fairly good seeing and illumination which leaves only the residual twilight vision; between the illumination which enables one to perceive things with some degree of definiteness and that with which one perceives chiefly forms and shadows. The exact position of this line is somewhat difficult to define, as it varies more or less in different eyes and under different conditions. At 0.5 meter-candle one has certainly not passed fully into conditions of twilight vision. Color perception, though much impaired, has not disappeared, and acuity, though failing, still remains in sufficient degree to permit casual reading, although with some little difficulty.* At 0.1 meter-candle a condition is reached where one depends almost entirely on rod vision. Acuity has been enormously reduced, and shade perception has become almost wholly dependent on dark adaptation. The point at which cone vision goes rapidly out of service, and rod vision as rapidly takes its place for what it is worth, is somewhere about 0.2 or 0.25 meter-candle, and daylight vision is not very dependable below 0.5 meter-candle. We have here, then, the physiological characters of the eye which are already well determined by investigation directed particularly upon them, as the basis of a physiological criterion of illumination. In twilight vision one sees things not as distinctly perceptible, but as dim forms and shades of uncertain boundaries and character. Only when the objects subtend a fairly large visual angle does one see them in the least clearly. This is the familiar vision of a bright starlit night or a dimly illuminated street. In its beginnings one cannot even distinguish large stationary objects from their background. The first perception is that of objects in motion, which seem to catch the eye more readily than when they are at rest. This is a familiar phenomenon in trying to pick up objects with a night glass at sea. They can be caught by sweeping when they quite escape detection on apparently slower and more careful search. This, too, is probably characteristic of the vision of nocturnal animals.

The next stage of vision presents objects either as vaguely silhouetted against a lighter background or as faintly lighted against

* One can, for instance, still read by the light of a candle 1.4 meters distant.

a darker background. By further increase of lighting some details begin to be perceptible, and when the illumination has passed the critical point of 1 meter-candle or a little more, to which reference has been made, further details come into view and objects take on a more natural aspect. The interesting theory of silhouetting as a feature of street illumination, which has been recently advanced, really concerns chiefly twilight vision and emphasizes the desirability under this condition of having a light background, not because one can see a dark patch on a light background any better than a light patch on a dark background, but because many things, and particularly the large things, which alone fall within the scope of twilight vision, are themselves commonly rather dark in surface, and, consequently, are not easily rendered lighter than the background. On the other hand, many objects are of surface lighter than, say, an asphalted street, and, consequently, are seen as light objects, while commoner than either condition is that of seeing an object in twilight vision only by its shadow, as one sees a distant pebble in the street in the beam of an automobile searchlight.

No illumination which depends chiefly on twilight vision can be seriously considered for the important purposes of street lighting. It has its useful place merely in enabling one to find the way. To be effective for the purposes of ordinary traffic, or as an adjunct to proper policing of a city, illumination must be sufficient to establish, at least to moderate extent, the conditions of cone vision. The wayfarer wants to distinguish the shadow of a post from a hole in the pavement before he is fairly upon it. The man who is driving along a street needs to see his way clearly without risk of running into the gutter, and the policeman should be able to tell a belated householder from a burglar using his jimmy on a front door. And, finally, in many places it is highly important to have enough additional light to distinguish faces readily, to see even trivial obstacles easily, and to read the numbers on houses or, if need be, consult an address book or a time-table. These considerations lead inevitably to the conclusion that unless one is prepared to meet the most exacting conditions of street illumination throughout the city he must be willing to classify the lighting that is to be undertaken, and to light each street according to its needs, bearing in mind the amount and kind of nocturnal traffic, and particularly the requirements of public order. We may here

consider streets as divided for the purpose of lighting into first, second, and third classes.

By first-class streets we mean the chief streets of a city from the standpoint of amount of nocturnal traffic and the requirements of the police. A chief street may be the principal business street of a city, that is humming with activity after nightfall. It may be a street leading to a crowded railway station where carriages and foot passengers are constantly circulating until late in the evening, or it may be a comparatively humble business street in a portion of the city where the police have found from experience that only constant watchfulness can keep down crime.

The ordinary streets of a city or town fall into another category. Traffic after nightfall is light or only moderate. The streets are reasonably orderly and the general conditions are such that neither from the viewpoint of the wayfarer nor from that of the policeman is brilliant illumination necessary. Such streets are the ordinary quiet residence streets of the average city and the business streets on which there is little traffic by night. These streets usually would figure up to two-thirds or three-fourths of the total mileage in the average city. These may be regarded as second-class streets from the illuminating standpoint, requiring good lighting, but not of the highest pitch of brilliancy.

Finally, there are, in every city, a number of streets which require practically very little illumination. They are mostly in the outlying portions of the city, sometimes scantily built up, and sometimes they are mere roads leading away from the structural part of the city, but still within its jurisdiction. For such streets it is necessary to provide only such illumination as will serve to mark the way and to render progress through them easy considering the conditions of traffic.

Occasional outlying streets, not at all important as residence streets, are still considerable traffic carriers, being through-roads from one part of the city to another, or from the city to some particular suburb or neighboring town. Such, from the standpoint of the illuminating engineer, are second-class streets rather than third-class streets. They demand the illumination required by considerable traffic. It is difficult to lay out any exact criteria for this classification, but there is no chief of police who could not, after a little reflection, make it with practical precision.

As to the intensity of lighting required for streets of these several

classes, the requirements have, by popular consent, been slowly and steadily rising. On the physiological basis which enables one at least to determine what lighting is necessary to reasonably good vision for various purposes, one can form a fair approximation of conditions to be met. First-class streets in constant use for dense traffic of one kind or another, or so classified from the police standpoint, certainly require reading illumination, and this is the kind of illumination that first-class streets get in most European and some American cities. The intensity of the illumination required is practically that already specified for public places, that is, an extreme minimum of at least 0.5 meter-candle, an average of fully double that amount. Theory and practice concur in holding that a street so lighted is well lighted. The same question arises here as regards the way illumination should be reckoned that was answered concerning the lighting of public places, and the answer is much the same for both cases. In each case it should be understood that the minimum cannot be permitted to apply to any considerable portion of the street area. The intensity here specified is substantially that deemed advisable by several foreign investigators and carried into practice with entirely satisfactory results.

As regards second-class streets the requirements are, of course, less severe. There should be, as a matter of convenience, light enough to recognize a friend without stumbling over him, to read an address, or see the number of a house comfortably. The average illumination for this purpose may be set at not less than 0.5 meter-candle, and the minimum should be high enough not to drive one into the physiologically undesirable condition of relying upon rod vision only. This would imply that the minimum should be nowhere less than about 0.25 meter-candle. Streets so lighted will be comfortably bright near the lamps, and the lighting will be as good as moonlight even at the darkest spot. This degree of illumination is excellently serviceable for the majority of second-class city streets.

Finally, we come to the third-class streets. If there is light enough to mark well the way and to disclose persons or vehicles in ample time for one to avoid them, it is sufficient. The degree of illumination required need not be greater than is afforded by bright moonlight, and should be fully as great as one finds in rather dim moonlight. It is illumination similar to that which is required for some of the park lighting, to which reference has been made,

ranging, say, from 0.30 down to 0.1 meter-candle, or thereabouts. At such low intensities it would be better to cut down the intrinsic brilliancy of the lights by screening, as in park lighting, so as not to spoil the dark adaptation which is necessary for utilizing so low a degree of light. In streets so dimly lighted the silhouette effect is rather marked, and it is not desirable to forego the advantage of a tolerably light surface on the street. The coefficient of reflection of roadways varies greatly according to their surface and the angle of incidence. At fairly large angles of incidence a dirt road or a dusty bit of ordinary macadam may give coefficients as high as 0.25 to 0.35; under similar conditions a dark pavement or a bit of oiled macadam may give coefficients from half of these figures down to as low as 0.05, which low values greatly increase the difficulty of proper illumination.

Considerations of economy in street lighting enforce such classification of streets as here described. Few cities can afford even at the present scale of public expenditure to light brilliantly any large proportion of their streets. If an attempt were made to light all the streets alike, there would be no first-class lighting at all. In small cities where the traffic is never very dense, and the use of the streets at night moderate, very little first-class lighting is required, and the amount necessary will diminish with the traffic. The burden of lighting, perhaps, falls more heavily on small cities than on large, owing to the large amount of street mileage compared with the assessable values. Hence, in such places, there will be, and properly may be, from the conditions, a relatively considerable amount of third-class lighting, but even so the cost of lighting is sometimes a serious matter. To keep down expense and yet to adjust the lighting conditions as well as may be, various attempts have been made to reduce the hours of lighting per year while yet meeting fairly the practical requirements. The earliest attempt of this kind, to which reference has already been made, was based on cutting out all the lights on moonlight nights. This scheme is apparent in the various moonlight schedules which have been used. Such schedules are all unsatisfactory, for the reason alleged against them from the beginning, — that the weather is no respecter of moonlight, and the nights near full moon are, in point of fact, sometimes as dark as the darkest. The only suitable lighting for cities of any importance is the all-night and every-night schedule. This is commonly based on starting the lamps

half an hour after sunset and extinguishing them half an hour before sunrise every day in the year. This amounts to a total of nearly 4000 hours per year. For any given locality this should obviously be based on local time and not on standard time. The intervals between sunset and lighting, and extinguishment and sunrise, are subject to some modification in the practice of various cities, changing with the season of the year, but the all-night and every-night schedule will be found to run between 3900 and 4000 hours, seldom being less than the former or exceeding the latter. If the full schedule as first suggested is to be modified at all, it is better to modify it in the morning hours than in the hour of lighting up, by reason of the greater traffic in the evening.

The so-called moonlight schedules vary considerably according to the tacit assumptions made regarding the effectiveness of moonlight, but run commonly a little over 2000 hours per year. A modified moonlight schedule, as used in a number of cities, starts with lighting from dusk to midnight every night, and takes on the moonlight schedule by extinguishment approximately an hour after moonrise after midnight. Such schedules run to about 3000 hours per year. The reduction in cost is not, of course, proportionate to the reduction in hours, so that the economy is to a certain extent rather apparent than real. A better plan is followed in some European cities of lighting all the lights every night from dusk to midnight or 1 o'clock, and then extinguishing part of them, sometimes every other light. Now and then this scheme is varied by having supplementary incandescent lamps attached to each arc pole and throwing these on during the morning hours. An arc pole thus arranged is shown in Fig. 155, and a beautiful example of similar practice using mantle burners as auxiliaries appears in Fig. 156. On the whole, this plan is likely to give better illumination than any form of moonlight schedule, but is less easily applicable here than abroad, since here most lights are on series circuits, while there the use of multiple connection is almost universal. No really effective scheme for cutting down the hours of lighting while yet adequately lighting the streets through the hours of darkness is reasonably to be expected. The only question that may fairly be raised is whether it may not be proper, say after midnight, on account of the changed conditions in the streets, to regard certain first-class streets as second-class streets, and hence to reduce the illumination in them by

cutting out every other light, which, in a liberally lighted street, if planned for in advance, is not impracticable. The same reasoning might apply to a few second-class streets. A consistent application of this principle might reduce the average hours of lighting per year from the 4000 of the all-night schedule to some point between 3000 and 3500 hours, depending on the number of lights affected. If rigorous economy in street lighting is absolutely necessary, this line is the logical one to follow.



Fig. 155.

Before passing to the practical design of street lighting, it is worth noting that while we have here reckoned the illumination as for normal incidence it is the usual practice abroad to reckon the horizontal component. This, as has already been seen, makes a very great difference in reckoning back from the required minimum illumination to the necessary power of the radiant. On the other hand, when reckoning the horizontal component one is at liberty to sum up the light received from both directions on a street or from all directions in an open space. The author per-

sonally prefers to consider only normal incidence and lights from one direction only, since it is this condition which must be considered in those uses of street lights which require the strongest illumination. If the lighting meets the severest requirement, it will also meet all the others. Objects of which the details are to be made out are generally held so as to be lighted from only one direction, and hence it is this which must be considered. In point of fact, the European practice is perfectly sound as regards the



Fig. 156.

results, because with a minimum requirement set quite as high as here indicated there is no doubt about getting sufficient normal illumination when the horizontal requirements are fulfilled. Furthermore, with the radiants commonly employed for street lighting and spaced so as to get the required horizontal component, the height of the sources above the street is such as to approximately fulfill also the requirement for normal illumination. For instance, the common spacing for arc lights in Continental cities is for chief streets about 30 to 40 meters, and the lamps

themselves being commonly hung 8 or 10 meters high, the angle of depression reckoned to the midway point rises to the vicinity of 30 degrees, and hence it is numerically a matter of indifference whether one reckons the light received at this incidence normally from a single lamp or the horizontal component from a lamp on each side. Thus, in effect, the two methods of measurement lead to practically the same result when the lighting fulfills the necessary requirement for intensity on either theory of procedure. The plane of illumination, that at which the required intensity should be found, is commonly taken at 1 to 1.5 meters above the pavement merely as a matter of convenience, it being very difficult to use a photometer near the pavement in the street on account of traffic. The vertical component of illumination has practically seldom to be considered in street lighting, save in its effect on near-by buildings, a matter which will be taken up presently.

Reviewing the nature of the problem of street lighting, that is, the illumination of a narrow surface extending in both directions from the source of light, it is obvious that the vertical distribution of light around the radius is a matter of great importance. A uniform spherical distribution is bad for the purpose, and the practical question regarding an illuminant for such use is how much of its effective flux of light can be conveniently turned downward upon the street. Light above the horizontal is not absolutely wasted, for it does some service by illuminating buildings. A radiant for street lighting should, however, be judged substantially by the lower hemispherical intensity, taking the lamp and its reflecting system together. Reflectors are useful with all varieties of street lamps merely for the purpose of deflecting downward light which would be otherwise lost toward the sky, and within limits the natural distribution from the source, that is, the distribution without any reflector, is a matter of no great importance, save as it may influence the convenient design of the reflecting system. A radiant which naturally and without a reflector casts a large proportion of its light into the downward hemisphere does not gain materially by that peculiarity unless it can show greater efficiency in luminous flux per watt than some other lamp with its reflector, or possesses important practical qualifications in its favor quite outside the matter of distribution.

Praiseworthy efforts have been made toward securing by reflectors a distribution stretching up and down the street rather

than radially in all directions. They have, unfortunately, made little headway as yet for reasons psychological rather than physical. Such reflectors are apt to be awkward in appearance, which is a great disadvantage by day, and require the maintenance of rather exact adjustment in order to do the most efficient work by night. Obviously, one could not push this sort of redistribution too far lest he should get an illumination approximating that which might have been obtained by a pair of automobile headlights facing up and down the street from a pole top and giving a capital light at a distance, but little near by. If, however, one could obtain a distribution which, instead of being circular, was an ellipse or similar figure having a major axis two or three times the minor, it would prove of great practical service in street lighting, but the improvement must not be at the expense of clumsy appearance or require constant care in cleaning to keep up its efficiency.

The modification of distribution is important from the standpoint of securing the proper spacing and height of lights. A distribution curve with its maximum 50 or 60 degrees below the horizontal is disadvantageous in that it compels a lamp to be placed high in order to bring its zone of maximum flux of light out toward the radius of minimum illumination indicated by the power of the radiant. On the other hand, a maximum within 15 degrees of the horizontal is almost equally bad, since then the most effective rays can generally be made to give the required minimum only from a lamp placed so low that considerations of avoiding glare make it undesirable. From a practical standpoint, a maximum somewhere between 15 and 30 degrees below the horizontal is most desirable, considering the available power and the permissible height of most commercial radiants.

These considerations bring one at once to the question of the spacing and height of lights for street lighting, and with this is inextricably bound up the troublesome question of large versus small units. Considering the usual circular distributions, it is readily seen that, basing judgment upon the required minimum and average values along the street, small units have the advantage in the total intensity required to meet given conditions. This total intensity, assuming radiants of the same distribution curve and placed at the best height, as indicated by equation (2), page 285, varies apparently inversely with the square of the

number of units assigned to cover a given length of street. In other words, to double the effective radius of action of a light, preserving these conditions of symmetry, requires four times the intensity, and so on. A glance at Fig. 157 shows the condition of things: a is the radius of action for a given mimimum for the source A, and b the similar radius for the symmetrically positioned radiant B_1; clearly, if a second small radiant B_2 be placed so that its radius of action touches that of its mate, one obtains from either disposition the same minimum illumination along the center line of the street, but the two radiants B_1 and B_2 need each give only one-fourth the light given by A. Moreover, since the circle

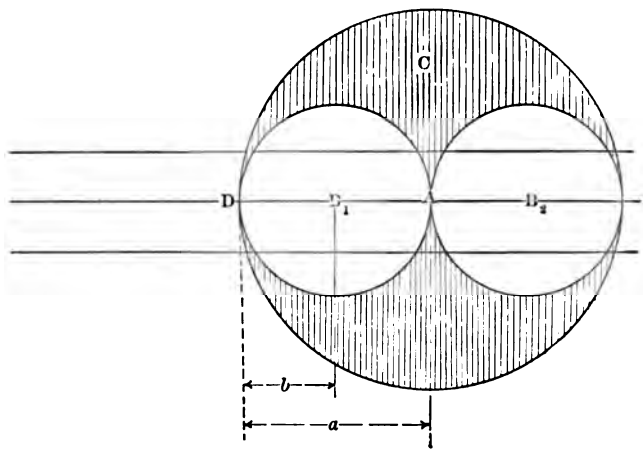


Fig. 157.

of radius A has four times the area of one of the circles of radius B, the total flux per square meter is the same in either case if symmetry is preserved, and the average flux through the respective cones of distribution would be equal. If this rudimentary computation were all there were to the matter, the case would be definitely settled in favor of small lights, but it is easy to see that this would lead to a *reductio ad absurdum*. For a single candle will give 0.2 meter-candle at a distance of nearly two and a quarter meters, and one may easily imagine the general darkness of a sidewalk, for instance, illuminated by candles nearly $4\frac{1}{2}$ meters apart. The secret of the matter is, of course, the great and useful flux of light required to give everywhere the fixed minimum intensity when using powerful illuminants.

In Fig. 157 if the light A, with its effective radius a, illuminates the circle of which it is the center, then the lights B_1 and B_2 equally illuminate their respective circles, but there is an equal shaded area C shown outside them which they do not light, and which is effectively lighted by the radiant A. Now, this large area is, from the standpoint of street lighting, not useless. If the houses stand well back from the street, it effectively affords them police protection; if they face close upon the street, some of the extra light is reflected from their surfaces and again becomes useful either as lighting directly the street or as furnishing a bright background against which dark objects may readily be seen. In other words while the minimum requirement, and even the average requirement, can be met by a much smaller total flux with small units than with large ones, the latter do in fact add greatly to the effectiveness of lighting for the purposes of its use.

Still further, if we replace one large light by n small lights under the assumed conditions, we not only get but one n^{th} the total flux for the same minimum, but we have to install and maintain n lights instead of one; and, since the investment and maintenance charges make up a large proportion of the total cost of any street illuminant, it often turns out that in an attempt to gain illuminating efficiency by decreasing the spacing and using small lamps there is no reduction in total cost commensurate with the loss of light flux. It is on this practical condition that the choice between large and small units usually depends. Also, if a certain minimum illumination be set, and a source of large power be replaced by smaller sources, these cannot be placed as B_1, B_2, B_3, B_4, Fig. 158, with their circles of limit illumination merely tangent, for that leaves much of the street below the allowed minimum. They would have to be placed overlapping, like B_5, B_6, B_7, B_8, or else the power of each smaller radiant must be considerably increased. Without going into the analysis of the requirement of overlapping enough to cover the street at the required minimum, it is apparent that the economy in flux secured by using small sources is much smaller than at first seems plausible, and the gain in cost smaller still. In point of fact, small sources are advantageous chiefly in second-class and third-class lighting. For first-class lighting they will rarely be found economical.

In thickly built-up and important streets the enormous light flux from powerful light sources is so useful for the general pur-

poses of illumination that it pays to utilize it. Particularly is this the case since it is true both in gas and electric lighting that the large units are of very much higher efficiency than the small ones. On the other hand, in streets requiring only moderate illumination, and particularly in streets low-hung with shadowing trees, the small light, which for efficient use must be hung rather low, as we have seen, is greatly to be preferred. In streets of the third class, where the conditions are such that there are no lateral reflecting surfaces to be utilized, the small unit is imperative. In everyday practice, especially with electric illuminants, the distribution curves of the small incandescent units and the much larger arc units, even when

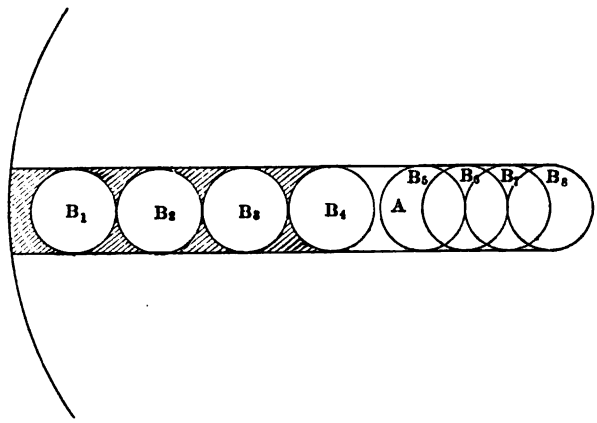


Fig. 158.

both are modified with the best available reflectors, vary very materially, so that in practice it is desirable to draw curves like L_n (Fig. 149), giving illumination as a function of distance according to the lamp, and thus make graphic comparison of the relative results to be obtained in service. When installed in diffusing globes both arc and incandescent lamps, and gas lamps as well, tend to a rounded type of distribution, which makes reflectors necessary to secure maximum efficiency. As a rule, all illuminants in American practice are mounted lower than they ought to be for efficiency. Powerful arcs or equivalent gas lamps should generally be mounted at least 25 or 30 feet above the pavement, and in case of the very large units even considerably more, up to 50 or 60 feet. Lamps of the type of the larger incandescent electric units and the corre-

sponding gas lights need to be carried to the vicinity of 15 feet high for economical results, varying somewhat with the type of reflectors employed. Practically, at the present time, one has to choose between radiants giving, say, 50 to 100 candle power, on one hand, or between 500 and 1000 on the other, only a few commercial sources running to still larger powers. This choice once



Fig. 159.

made, the considerations already given show the spacing which must be maintained in order to give the minimum illumination and the average illumination, respectively, suitable for the various classes of work, and the characteristics of the lamps used hold this spacing within narrower limits than seem at first sight probable.

In much first-class lighting extra light received from shop windows and signs affords valuable reënforcement during the hours when most light is needed. This illumination is very commonly as

great as that from the street lamps, and sometimes several times greater. It is useful, but one cannot safely count much upon it, since it is largely influenced by habit.

In placing lamps, large or small, it is imperative that they should be so located that their useful light flux can be utilized. This condition is often violated by placing lamps where their light is very largely cut off by trees. By far the best method of placing street lamps from the standpoint of illumination is the cross-suspension. The best form of this, very general in Continental cities, is, in closely



Fig. 160.

built streets, the cross-suspension from buildings, well shown in Fig. 159. In this country there is seldom proper provision for this, so that one is driven to the clumsier suspension between poles. A street adequately lighted by lamps upon cross-suspensions may often fail of it when side poles are used. Nevertheless, owing to our local conditions, it is more general to use side poles. These are too often ugly in design and hence offensive by daylight. There is no excuse for this, save petty economy, since poles of graceful design are readily obtainable. A capital example of Continental practice in side poles is shown in Fig. 160, a light design

of steel tube springing from a cast-iron base, and bearing a flame arc. If powerful lights are used in streets which must be equipped with side poles, long mast arms, ugly as they are, are practically extremely useful. In fairly open streets, lamps bracketed out from 2 to 6 or 8 feet from the curb give satisfactory results, and these methods of suspension are available for all illuminants, electric or other. Abroad these fixtures are often systematically placed on buildings whenever possible, thus relieving the street of poles. A good example of such brackets appears in Fig. 161 applied both to



Fig. 161.

an arc and to a gas lamp. Where there are many trees small units bracketed fairly well out from the curb are by far the most successful illuminants, although there may be local reasons for preferring larger ones in cases where rather brilliant lighting is necessary, and there is practical or æsthetic objection to increase in the number of posts. In final warning in the matter of spacing and height, it must be said that only a few of the most powerful sources, as yet very little used in this country, are capable of giving the illumination required for first-class streets, over a radius of as much as 150 feet. Ordinary arcs spaced at 400 to 500 feet, as is too often the case, are rarely adequate even for second-class lighting, on account

of the long and very faintly lighted spaces which must exist. Only the most powerful radiants may be thus spaced.

The proper placing and screening of lights to avoid glare is another important matter. Glare is due to a number of causes, but practically it is chargeable to the use of sources of too great intrinsic brilliancy, or too great absolute intensity at short distances. A powerful light, even at moderate intrinsic brilliancy, when viewed at short range floods the eye with light to an extent that interferes seriously with vision. It also cuts down the pupillary aperture to half or one-third of its normal value, which greatly diminishes the visibility of the less brilliantly illuminated part of the field, and, more than anything else, it spoils the dark-adaptation which makes enormously greater difference than anything due to pupillary reaction. At considerable distances there is very little trouble due to intrinsic brilliancy. As, however, one is constantly coming into close range with street lights, protection against too high brilliancy is imperative in case of powerful radiants, either gas or electric. The smaller lights, sending much less luminous energy to the eye, produce less disturbance by their glare, and diffusion, while desirable, is less necessary, save when one falls to third-class lighting, in which dark-adaptation is all-important. No trouble would be experienced with any ordinary illuminants if screened behind mildly diffusing globes. Unless lights are so screened the minimum illumination must be raised very materially for the same ease of seeing.

Owing to the comparatively weak illumination in most street lighting, methods of measuring it are somewhat troublesome. There is always difficulty in photometry with very weak light on the photometer screen, and this is aggravated in street work by frequent unsteadiness of the lights, and in some cases by their great difference in color from the lights used as comparison standards in field work. Comparisons of illumination near and below the minimum specified for second-class lighting are peculiarly fallacious, owing to the disturbing effect of varying adaptation. Indeed, it is not putting it too strongly to say that comparisons of such kind, say at 0.2 or 0.3 meter-candle and below, are unreliable, even when made with the best available field photometers. Consistent results may sometimes be obtained by a single observer, or by two observers so used to working together that their results are in no wise independent, but consistency is no proof of reliability.

Acuity photometers sometimes used for such cases are even worse, and their results are not worthy of serious consideration as expressions of anything more than individual opinion. These instruments violate a fundamental rule of physical measurements, in that the quantity sought varies enormously with the one actually used for measurement. By all means the most reliable method of determining illumination is computing it from the known distribution curves of the radiants, taken not with carefully cleaned and adjusted lamps under laboratory conditions, but with lamps in their ordinary service condition run from the commercial wires or gas mains, even though tested in the laboratory. The effect of dirt on the inclosing globes is so serious that it must be taken into account in this way.

For similar reasons the intercomparison in the field of different street illuminants is very unsatisfactory. One can tell photometrically pretty nearly what a light is doing, and can judge in a general way of the effectiveness of that particular lamp. He cannot form, however, a correct judgment of the relative performance of two lamps of different kinds unless they are conspicuously different from each other, since he does not know ordinarily whether each of the lights is burning under its normal conditions, whether one of them is ill adjusted, and with a globe considerably dirtier than the average, or whether the other has been carefully adjusted to give more than its normal duty, and is as clean as care can make it. Of course, anyone can tell a clean globe from a dirty globe, but he can do nothing more than guess how much difference to ascribe to this cause.

One meets a good many cases of skillful jockeying with lamps, and even with the photometry of lamps, and while field comparisons may be interesting as experiments, they do not form a suitable basis on which to found lighting contracts which may involve hundreds of thousands of dollars during their terms. And particularly is this stricture directed at reading tests so called, at low intensity, which are largely matters of adaptation and adroit manipulation of the conditions. It is well within bounds to say that they are generally open to suspicion, whether directed by the contractor for illumination or by critics inclined to be captious. They are sometimes called "practical," but experience teaches one to define a "practical" test as a test cunningly devised to divert attention from the objectionable points of the thing tested. Their

proper sphere is merely to furnish one item of information, and not a very important one, about what the lights are doing. Two lights, both in good condition and adjusted and operated by impartial observers, can be photometrically compared in the field with a reasonable degree of precision, but never any more satisfactorily than they can be compared under properly arranged laboratory conditions.

To summarize briefly the characteristics of modern illuminants for street service, one may divide them into five generally familiar types: 1, flame or luminous arcs; 2, carbon arcs; 3, tungsten incandescent lamps; 4, high-pressure mantle gas lamps; 5, low-pressure mantle gas lamps. As class 4 is little used in this country, one need say no more here than that the high-pressure gas lamps are powerful illuminants comparable in intensity to the flame arcs, that is, running from, say, 1000 to 3000 candle power, and of sufficiently good color and steadiness to meet all street requirements. The low-pressure mantle gas lamps are usually of 100 candle power or less, like tungsten incandescent lamps, and when properly maintained bear the same relation to the high-pressure lamps that the incandescent lamps do to the arcs. Considered merely as radiants for the street, they have no peculiarities of color or distribution which separate them from other radiants.

To summarize the arc situation already treated in Chapter VIII, the flaming or luminous arcs are of three general classes: 1, arcs burning carbons of which one or both are mineralized, commonly with calcium fluoride for yellow light or with other substances for a whiter light, with converging carbons pointed in an acute angle downward; 2, vertical carbon flame arcs, commonly known as the system Blondel lamps, burning similar carbons heavily mineralized and in vertical position; 3, lamps burning electrodes, at least one of which is charged with metallic oxides, most commonly oxides of iron and titanium in various proportions. Such are the magnetite arcs in common use. In this case the positive electrode is of copper and the active mineralized one is an iron tube packed with the oxides. All these lamps may run to high powers, from 1000 to 2000 or 3000 candle power, in the effective zones of the lower hemisphere, and with mean lower hemispherical candle power ranging up to 2000 or more. The converging carbon lamps from the position of the electrodes tend to throw the light downward, to an extent that is not readily corrected by reflectors.

They should hence be placed specially high with respect to the spacing. They are reasonably steady and have proved very satisfactory illuminants. The vertical carbon flame arcs give a distribution which lends itself rather more readily to the successful use of reflectors, and the maximum light falls, with properly designed reflectors, within the useful zones from 15 to 30 degrees below the horizontal. They are, on the whole, more efficient for street service than the converging carbon lamps, and they are made even up to 3000 candle power and more. The lamp described with reference to the lighting of Copley Square is one of this class, and gives an intensity of about 2500 candle power, including the opal globe, in average condition, at the angle of about 15 degrees below the horizontal. This advantageous distribution is due largely to a well-placed reflector. The specific consumption of the large flame arcs of both varieties is somewhere in the region of about one-quarter to one-third watt per candle. The metallic oxide lamps have for their chief advantage a rather long-burning electrode, giving within a reasonable length of pencil of 8 or 10 inches a life of 50 to 150 hours. The products of combustion, being brownish oxides, tend to smut the globes, and have to be gotten rid of by special draft channels which carry the fumes away. The commonest of this type is the so-called magnetite lamp, which has proved extremely successful as an illuminant in practice. Its specific consumption, when put in a light-opal globe, ranges in the region between one-half watt and 1 watt per candle, according to current, as in other arc lights. It furnishes a suitably steady light in the vicinity of 1000 hemispherical candle power in the moderate sizes, and nearly as much again as an extreme figure. The color is good and the steadiness adequate, and the lamp has been rapidly driving out the older forms of arc, being preferred to other flaming arcs in this country on account of the long life of the electrodes. The magnetite lamp is operated at from 4 to 6 or 7 or even 10 amperes, the latter rarely, and the voltage at the arc is about 80. These characteristics make it very convenient for use on series circuits.

Ordinary carbon arcs are becoming obsolete for street service. They run in sizes from 600 or 800 mean hemispherical candle power to as low as 200 or 250. The former figure belongs to the few powerful open arcs that are in existence, the latter to some of the alternating-current inclosed arcs. The specific con-

sumptions range from a little better than 1 watt per candle in the former case to above 2 watts per candle in the latter.

The tungsten incandescent lamps are too well known to need further comment here. They are ordinarily available in candle powers from 40 to 100, and lamps of 200 or 300 or even 400 candle power have been produced, but have not come into much use up to the present time. The tungsten lamps form the main reliance of street electric incandescent lighting at the present time. Their specific consumption is in the vicinity of $1\frac{1}{4}$ watts per candle, and their distribution, when suitably equipped with reflectors, well suits street lighting. The carbon incandescent lamp, like the open-flame gas lamp, is rapidly becoming obsolete.

Contracts for street lighting are essentially contracts for service on the part of a public supply corporation. A city does not buy merely a given number of kilowatt hours per annum, nor a specified number of arc or incandescent lamps of certain candle power. It does buy, in fact, light and service with specified illuminants, including current or gas, as the case may be, maintenance of the lights in first-class working condition, and the operation of them for certain specified hours per year. It is the character of the service that determines the difference between good and bad lighting. One may specify a certain consumption of gas or of watts in a lamp and still get extremely bad service. He may also specify a certain minimum illumination and get extremely bad service. If he tries to buy illumination as such, he faces the practical difficulty of measuring it with sufficient precision for the maintenance of contractual relations. He can tell with the photometer whether the lights are performing well or badly, but he cannot by any means estimate the faint illumination customarily used in this country as a minimum with a degree of precision that should pass any conscientious auditing department. Buying and selling illumination as such is simply courting litigation.

The soundest basis for a contract between a supply company and a municipality, for street lighting, is for service during specified hours per year, and with proper allowances for "outages," of specified types of lamp, the characteristics of which can be evaluated, such lamps being placed in accordance with the requirements of the city. If they are placed so as to meet such requirements of illumination as have been previously set forth, and are properly maintained by the operating company, the illumination will be

found adequate, and its value can be on the average reckoned from the known characteristics of the lamps with far greater precision than it can be measured on the ground. The location of the lamps should be done under the direction of the municipality so as to produce the illumination required, but if any definition of the illumination is specified, both the minimum and the average should be included. Lighting on the basis of a contractual minimum only is certain to result in bad lighting. Judging by average illumination alone is merely an incentive to unequal distribution, but when the illuminants themselves and the terms of their output and operation are properly specified the illumination will take care of itself.

CHAPTER XIII.

DECORATIVE AND SCENIC ILLUMINATION.

THERE is a certain transitional region between street and other exterior lighting of a purely utilitarian character, and the illumination in which the decorative element is predominant. In the lighting of public places, as has already been pointed out, the lighting fixtures and the distribution of the illumination should have relation to the decorative possibilities of the place. This



Fig. 162.

condition is realized particularly in the lighting of semi- or wholly-architectural things, like bridges and esplanades, the entrances and courtyards of public buildings, terraces, ornamental bits of parkway, and the like. In such places not only must the illumination be harmonious and without glare, but the fixtures themselves by day and by night should be appropriate and decorative. Usually they violate all the canons of science and good taste, the fixtures having been picked out of the catalogue of some persistently intrusive salesman by a committee of politicians.

The lighting fixtures in places where their purpose is essentially decorative require a fine artistic instinct to secure proper design, and close supervision to secure illuminating efficiency, and these two are seldom found together. As an example of the good effects which may be secured by properly designed lighting fixtures, the bit of the Thames Embankment, shown in Fig. 162, is one of the best that has come under the author's observation. The posts are highly decorative in the modeling and are surmounted by opal balls fitted with tungsten lamps which make the standards beautifully effective at night, casting an ample mellow light along the way. A second fine example of lighting under similar circumstances is shown in Fig. 163, — the Quai de Mt. Blanc in Geneva. Here



Fig. 163.

again the tall and ornate fixtures are given a decorative motive which harmonizes exceedingly well with the location and environment, and the effect by night is altogether beautiful. The fundamental principle in all such lighting is that the fixtures must form a suitable part of their environment, and be designed as objects of art and not as samples of ironmongery.

In most instances the larger sizes of tungsten lamps are the best sources of light for such cases, though now and then arc lamps may be used, and in case of need the larger mantle burners will give a good account of themselves. It is not the particular kind of light which counts in this class of work so much as adequate amount and steadiness combined with suitable fixtures. About the entrances of fine buildings, public or private, suitable lighting

is less rare than in parks and other public places, for the simple reason that such matters are usually in the charge of the architects who are not without artistic instinct. Little need here be said regarding fixtures except to emphasize the fact that elaboration in design is not desirable unless a rather large appropriation can be made to cover the expense. If fixtures must be had at moderate cost, they must be simple, and probably will be none the less artistic for this qualification. As an example of simple and harmonious treatment of even so utilitarian a source of light as an arc lamp, note Fig. 164 from the entrance to a German theater. One need not, however, multiply instances of this sort; it is only necessary to impress the fact that extreme elaboration is not necessary to obtaining the desired results, but that if elaboration be attempted it must be carried through consistently without trying to shirk expense.

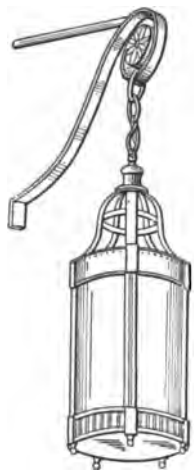


Fig. 164.

To pass to the next phase of the subject, we must consider the lighting of structures, that is, the branch of illumination which is intended for decorative purposes to bring into prominence by night, buildings and monuments which are of artistic value by day.

It is never a work of necessity, although often desirable as a suitable appreciation of public structures which are in themselves worth seeing. Its laws, are, therefore, rather those of æsthetics than those of engineering, albeit the engineering requires peculiar adroitness in order not to defeat the æsthetic end sought. No class of lighting is, upon the whole, worse done, and the few masters of it, like the late Mr. Stieringer, have excelled rather by instinctive genius than by the application of the precedents of engineering.

As to the character of such lighting, it varies very widely, from the mere emphasis of salient details, or strong accentuation of particular objects, to the securing of startling scenic effects by flooding the surface with light or marking it out in lines of fire.

There are, indeed, two distinct classes of structural lighting, one bringing forcefully out, as far as may be, the daylight values of the object; the other, being the evolution, with the structure

as a basis, of artistic results in no wise akin to the effects of daylight. An example of the former case is the lighting of a monument, or of the façade of a building, so as to secure the full artistic value of the structure. Into the latter class falls naturally the display lighting of expositions and of special buildings and grounds, *en fête*.

The methods of illuminating structures are as various as the purposes for which the illumination is used. They may include merely the skillful application of ordinary illuminants, the enforcement of their effect by reflectors and searchlights, and the employment of small lights in an infinite variety of ways. The former methods find their largest application in lighting monuments and façades; the latter, in the production of scenic effects, in which the more powerful illuminants also may be made to play a most useful part.

Broadly, one may divide the classes of effects sought in lighting structures into those which have to do with the lighting of surfaces as a whole, those in which particular portions of surfaces are sought to be emphasized, and those which are essentially scenic and decorative in their effects and bring into prominence not surfaces but outlines. Each kind has its legitimate field, but its applicability depends in each case on quite different criteria. In general, the first two classes belong essentially to structures beautiful in themselves, while the last named, if skillfully carried out, which it generally is not, may lend distinction to things comparatively commonplace.

The superficial lighting of structures, as of the whole façade of a great building, is both difficult to do well and somewhat expensive. Particularly does its apparent expense run high, inasmuch as it is a case of deliberately pouring a flood of light on an exterior, generally from a source quite outside the building. The sources of light have a certain detached character that brings their cost sharply into view, while the same expense applied to even inefficient and inartistic grouping of small lights about the structure itself would fail to produce the same psychological effect on the auditing department.

In order to be effective, surface lighting must be both somewhat brilliant and very carefully directed. The greatest difficulty in getting a satisfactory result is that due to obtaining the proper direction of illumination. The façade of a building ordinarily is

lighted obliquely from above, without sharp shadows, save when the building is in brilliant sunshine. The strength of the illumination falling on a building by daylight may easily run to many hundred or even thousand meter-candles. It is enough, at all events, to bring out a wealth of fine detail even in a very dark building.

The coefficient of reflection of a building surface is usually rather small, say from 10 to 25 per cent, at ordinary angles of view, rising notably higher than this, say to between 30 and 40 per cent, only in case of buildings of very light and clean brick or stone, or of very lightly tinted concrete. In most cities the accumulation of dirt due to smoke keeps the reflecting power low. Hence it takes strong lighting, such as is to be had by daylight, to bring the architectural details of a building out at anything like their full value, if they are of any delicacy. In the artificial lighting of a façade, the direction of the illumination is necessarily rather from below than from above, and unless the illumination is deliberately planned to provide a dominant direction of lighting the effect is usually to flatten out the projections and sink the detail into insignificance. Light coming indiscriminately from all azimuths along the front is likely to give a disagreeable shadowless effect, and the delicacy of the surface of the structure is quite lost. The illumination should, therefore, be given a predominant direction so as not to lose the effect of light and shade, and, in fact, somewhat to exaggerate it in order to bring out something of the texture in a light dim compared with daylight.

If we could bring ourselves to a really progressive frame of mind, searchlights and reflectors used from points well outside the building to be illuminated could be made to produce much better results than are obtained by any other means, and there is much to be said for so lighting a façade that it shows its architectural value as it is, and not with the addition of freakish lighting effects generally undignified and sometimes ludicrous.

A façade with striking features, large and dignified, is comparatively easy to illuminate, while one with a wealth of fine detail requires so much light that the feat of dealing with it adequately is almost impossible.

Searchlights and reflectors form the best means of getting adequate surface lighting where large areas are concerned. A slight digression regarding the searchlight for this and similar purposes

may be here permissible, since the properties of the searchlight as an illuminant are generally imperfectly understood. From the standpoint of luminous flux, the case of the searchlight is a comparatively easy one. From the energy consumed in the arc and the structure of the lamp, it is not difficult to form an approximate idea of the lumens which emerge from the system. Then the illumination received on any surface is this total flux divided by the area of the surface in square feet, if one wishes to express it in foot-candles, or in square meters if he chooses, as is preferable, the meter-candle as the unit.

The illumination delivered by a searchlight system is

$$L = \frac{4\pi ei\eta}{\pi r^2} = \frac{4\,ei\eta}{r^2},$$

where e is the voltage at the arc, i the current, and η is the specific efficiency in mean spherical candle power per watt $\times$ the net reflective coefficient of the mirror system, r being the radius of the incident beam.

Assuming

$\eta = 1$
$e = 80$ v.
$i = 50$ amps.
$r = 10$

$$L = \frac{4 \times 80 \times 50 \times 1}{100} = 160 \text{ meter-candles.} \qquad (1)$$

Or at the just assumed voltage and radius, 100 meter-candles would require

$$i = \frac{Lr^2}{4\,e\eta} = \frac{100 \times 100}{4 \times 80 \times 1} = 31.2 \text{ amps.} \qquad (2)$$

Or to obtain η,

If $L = 100$
$e = 80$
$r = 10$
$i = 40$

$$\eta = \frac{Lr^2}{4\,ei} = \frac{100 \times 100}{4 \times 80 \times 40} = 0.78. \qquad (3)$$

η expresses the specific efficiency of the searchlight system as a whole, and should be the subject of systematic experiments.

This rule holds for cases in which the cosine of the semiangular aperture of the beam is near unity, i.e., when the measured illumination is substantially normal; (1) and (2) are subject to a similar limitation. As to the absorption by the atmosphere, it is in clear weather small, amounting, from Sir William Abney's data,

to about 15 per cent for the chief luminous rays in transmission through the whole thickness of the atmosphere.

The flux measured in lumens remains the same, barring absorption by the atmosphere, at all distances from the light, and the intensity at the surface illuminated becomes merely a matter of the area of the beam.

Without the use of lights comparatively distant from the surface to be illuminated, surface lighting becomes increasingly difficult. It can be carried out to a certain extent with lights on the structure itself, but the effect is not good if more than special portions of the surface are so illuminated. It is an extremely difficult matter to light a surface adequately from a point near itself without either making the light sources too conspicuous or rendering the illumination very uneven. Moreover, lighting at nearly grazing incidence distorts all surface details and destroys their delicacy. It may even produce extremely bizarre and unpleasant effects. Striking examples of the failure of illumination at grazing incidence may be found in the case of attempts to light paintings from reflectors placed near the plane of the canvas, the effect of which is to bring into glaring prominence every brush mark, quite destroying the effect the artist intended to produce.

Only in rare instances can the lighting of a building by sources placed upon it prove effective, and then only when comparatively limited areas are sought to be illuminated, or when the effect intended to be produced is not that of daylight illumination but that of a special form of decoration. A striking success in this line was the lighting of the Metropolitan Life tower in New York during the Hudson-Fulton celebration, in which advantage was taken of the structure of the higher parts of the tower so to place the lights upon it as to bring the massive detail high in air into brilliant prominence against the sky. Fig. 165 gives a rather inadequate view of the conspicuously good result.

Spot lighting is, except in such instances as that just mentioned, generally confined to the illumination of monuments or groups of statuary. It too frequently would be better to leave these to the kindly concealment of night, but now and then they are worth the effort at illumination. As a rule, attempts to light such things fail from placing the lights too near, and thereby producing distorted shadows which quite destroy the artistic value sought. Only massive, plain surfaces, such as the Washington Monument in



Fig. 165. — Illumination of the Metropolitan Life Tower.

Washington presents, can be adequately lighted from sources placed near the base. Monuments of ordinary types should be illuminated, if at all, from distances several times their height.

Now and then on white surfaces, colored illumination can be used with beautiful effect; but these cases are rare and chiefly confined to temporary exposition work, in which there is small chance for time to destroy the high reflecting power of the surfaces necessary to brilliant effects.



Fig. 166. — How not to do it.

Exposition lighting is an art almost by itself, owing to the immense areas that have to be dealt with, and the extreme difficulty of getting suitable locations for lighting buildings from the outside. The main reliance in such work has in the past usually been outlining by myriads of small incandescents. If skillfully done, that is, done with due reference to the magnitudes and distances of the buildings so as to preserve the *ensemble* effect by night, the result may be extremely beautiful; but if the salient features are wrongly

chosen or the ornamentation is exaggerated, nothing can, on the whole, return less of artistic value for the energy employed. At its worst, outlining becomes a mere symbolizing of structural lines, as a child might draw them upon a slate. Fig. 166, a night photograph of an important building, during the Hudson-Fulton celebration, will serve as a horrible example of how not to do it. Restraint and keen appreciation of the features of a building worth outlining are necessary to the securing of good results, otherwise the eye will simply be confused by a multitude of lights with nothing to indicate their distance, and will find even individual buildings distorted by the wrong spacing or placing of the lights. Fig. 167,



Fig. 167. — The Electric Tower at Buffalo.

the electric tower at the Pan-American Exposition of 1901, is a beautiful example of the harmonious application of correct principles in decorative illumination, a masterpiece in its way, due to the consummate skill of the late Mr. Stieringer. Skillfully used, outlining may confer by night singular beauty on structures either commonplace or grimly utilitarian by day. Very striking examples of the decorative use of outlining and similar illuminative devices were shown during the Hudson-Fulton celebration in New York. No one who saw the East River bridges and the stacks of the

Water-side station failed to recognize the great artistic value of judiciously strung lights. The bridges from a distance were things of glory instead of grimy skeletons of cable and girder, while the stacks, by day merely solid and purposeful, became beautifully decorated symbolic towers of light. A fine example of graceful outlining was furnished in the illumination of the Eiffel Tower at the Paris Exposition of 1900, shown in Fig. 168.

In attempting to outline buildings, it is generally found best to emphasize some of the special features as well as the general con-



Fig. 168.

tours, so that the illumination is not only structural but decorative. In great measure success depends on the judgment of the engineer in fitting the spacing and power of his lights to the particular work in hand. Fig. 169 gives a night view of the Electricity Building at the St. Louis Exposition of 1904. It is an admirable type of combined outlining and decorative lighting, planned for a viewpoint across the lagoon. In such work it makes a very material difference whether the lighting as a whole is to be viewed from a distance or near by, from practically on a level or from below. As to the proper spacing of lights for general service in such work, it usually runs in practice from 8 inches to 2 feet, while in some

instances even these dimensions may be passed. The fundamental thing is to proportion the spacing to the ordinary viewing distance, so that the lights will neither run together in a blurred line nor present a scattered appearance.

The former limit in the last resort depends on the power of the eye to separate two neighboring luminous points. Many experiments on this sort of visual acuity have been made, and they may be summed up by saying that the eye distinguishes two bright points as separate very easily when they subtend a visual angle of



Fig. 169.

5 minutes of arc; fairly well when they subtend an angle of 3 minutes; and under favorable circumstances, and with difficulty, when they subtend an angle of 1 minute. These figures are somewhat influenced by the actual darkness of the background, and by the actual intensity of the lights with respect to their production of irradiation.

Now, an angle of 1 minute is subtended by two points distant from each other by 0.0003 of the viewing distance. The 3-minute angle, therefore, corresponds nearly to a separation of one part in a thousand, and the 5-minute angle to one part in six to seven

hundred. Around about this latter figure good results are obtainable, and the separation of lamps can often be carried up to 10 minutes of arc with advantage. Closer spacing than 3 minutes is seldom desirable, since only in rare cases does one wish to produce the effect of continuous lines. There is, therefore, a wide range in spacing permissible with which to take account of the important questions relating to perspective. The frontispiece shows a remarkably distinguished and successful use of festooned lights in the Court of Honor at the Hudson-Fulton celebration of 1909. Two blocks along Fifth Avenue, from 42nd Street to 40th Street, were included, and 36 massive pylons were erected along the avenue to bear the central decorations of the occasion. The night effect was very striking and beautiful, though the plate is marred by the streaks due to the headlights of motor cars.

The effect of the spacing, intensity, and alignment of lights upon nocturnal perspective has played a very small part heretofore in illumination, although it is well understood as a practical art by the masters of stagecraft. Ordinarily, one wishes to preserve the normal conditions of perspective in undertaking artificial illumination. This requirement implies a generally uniform spacing of lights, since the eye instinctively judges the length of a line of bright points by their apparent approximation as they reach the vanishing point.

In the case of lines of light generally viewed obliquely, the spacing may, however, be widened, since the visual angle between points in such case corresponds to a narrower spacing than when viewed normally. For example, lines of lights festooned lengthwise of a street may be spread far more widely than usual, while still preserving unity of effect, since they are, upon the whole, viewed always from a very oblique angle. Lines of festoons thrown crosswise of the same street are always seen normally to their length, and consequently should revert to standard spacing.

There are, however, many instances in which lights can be advantageously used, not to preserve the perspective, but to force it and to create illusions of distance. If one were so placed as to look down a long street, viewing it from a fixed point and not passing along it, it would be possible to produce extraordinary illusions of perspective by varying the spacing and the intensity of the lights. In the absence of any permanent objects upon which the eye can fall to determine distance, it is compelled to judge very largely by

the apparent perspective. A row of lights down each side of the street, diminishing in spacing or intensity, or both, would infallibly call to the mind the conception of indefinite distance stretching out into the night. If, on the other hand, the spacing were progressively increased and the intensity also increased, each within limits, the effect would be to produce an apparent shortening of the vista. These effects may be very pronounced even where there is no deliberate angular shifting of lines in the field of vision to produce illusions of perspective. Lines converged toward an artificial vanishing point abnormally near are, of course, familiar in stagecraft, and by adjusting the stage setting on a diminishing scale, with lines thus converged, it is possible to create in great perfection the illusion of a far-reaching space, even on a stage of very modest dimensions.

These effects, emphasized by powerful lighting in the near foreground, diminishing toward the rear, are quite familiar, and are often, in fact, overdone. When properly carried out they are immensely striking in effect. The forcing of perspective in this way and the taking advantage of the characteristics of vision to create illusions of direction and distance have been known at least since the time of the builders of the great monuments of Greece. Not only did these masters swell their columns slightly to overcome the illusion of outline presented to the eye at a relatively near viewpoint, but they even drew the columns together and toward the structure slightly at the top, as in the Parthenon, by an amount not large enough to be conspicuous, yet sufficient to accentuate the height. They knew well, too, how to proportion the scale of their ornamentation to the viewpoint, and seemed by a fine instinct to have discovered much that in practice has been too often forgotten in the centuries that have intervened. Now, this same sort of effect can be produced by judicious modification of the external lighting of structures. For example, the author has had occasion to overcome the tendency of a building, somewhat too tall for symmetry, to vanish into indefinite height as night came on, by powerfully emphasizing the decorative lighting of the cornice and spacing a horizontal line of lights across the front, disproportionately close compared with those above. The effect, as the lights come on in a dark evening, and the towering top emerges out of distant blackness into its proper position, is somewhat striking. By such devices as these one can not only overcome the curious distortions produced by night, but can, if necessary, create a wide

variety of illusions on a large scale, less perfect, perhaps, but almost as striking, as those worked out upon the stage.

The effect of the intensity of lights in such work is worth noting. It is a curious fact that the eye carries so very imperfect conceptions of intensity. For outlining work, signs and similar uses, 8-candle-power lamps are practically as good as 16's, and 4's about as effective as either. The author has actually changed 8-candle-power lamps for 4's on one line of a sign, leaving the others unchanged, without producing any noticeable difference whatever when the sign was viewed from the ordinary distance of several hundred yards. Any brilliant spot, however small, seems to serve the purpose, and the size of the lamps used is really determined rather by the ability to procure them than by anything else.

Recent progress in sign work has tended to smaller and smaller lights with positive gain in the effect produced. In attempting, therefore, to create illusions by changing the size of lights, the change has to be an exaggerated one. The use of colored lights in such cases as we have under consideration has been barely touched upon in practice. It is made immensely effective in signs, and has been used successfully in some exposition work for purely decorative purposes, but color as an element in scenic illusion off the stage has scarcely been tried. It possesses, nevertheless, possibilities which are worth much more intelligent study than has yet been given them.

Colored light can be effectively used with reflector arcs, on white surfaces, on cascades, in fountains, and the like, but is seldom successful when tried with incandescent lamps, save on a very small scale. The difficulty lies in the dimness of colored bulbs and the failure of attempts to get delicate tints in this way. Colored glass bulbs are expensive, and coated bulbs accumulate dust and are seldom weatherproof.

Much decorative lighting is for temporary purposes, but with the present facilities for obtaining current and the temporary mountings that can readily be obtained, the work is comparatively easy.

Special receptacles for signs and decorative designs are now made in convenient form for quickly putting together, and enable temporary work for special occasions to be very easily done. Fig. 170 shows one useful form of mounting device, in which the weatherproof receptacles can be quickly strung together with

clamps and held neatly spaced in any way desirable. For decorative work on a considerable scale the retaining clamps would, of course, be much longer than here shown.

There is a fine chance for art in turning on the lights in architectural and other decorative work. The water rheostat, bringing all the lights simultaneously from a dull-red glow to full brilliancy, is by far the most comprehensive scheme for the purpose. In the absence of this, or in permanent work of which only a part is regularly used, the circuits should be so arranged as to allow a perfectly symmetrical development of the lighting without throwing on a very large current at any one time.

In any and all decorative work the illumination must be subordinated to the general architectural effect. Sins against art in this respect are all too common. Imagine, for example, a Doric temple with arc lights at the corners of the roof and festoons of red,



Fig. 170. — Chain of Receptacles.

white, and blue incandescents hung between the columns. About a structure of such severe simplicity lights must be used with extreme caution, while more ornate buildings can be treated with far greater freedom of decoration.

It requires both fine artistic instinct and great technical skill to cope adequately with the problems of decorative illumination. The tricks of the art are manifold, and mostly meretricious. The facility with which electric currents may be manipulated is a continual temptation to indulge in the ingenious and the spectacular without due regard for the unity of the results.

Another class of work, hardly a part of ordinary lighting, but yet of considerable interest, is the use of lights purely for decorative purposes in interiors, in halls and auditoriums for special designs and as part of the decorative scheme of ballrooms and the like. This is really a branch of the art due entirely to electric lighting — since only by this means can it be rendered fully serviceable.

Most branches of illumination are in a measure independent of the particular radiants employed. But the ease and safety with which incandescent lamps can be installed render them peculiarly applicable to such interior work.

In operating on a comparatively large scale, all sorts of decorative designs can be carried out by means of 4-c.p., 8-c.p. or 16-c.p. lamps strung together in receptacles, in the manner of Fig. 171, or otherwise temporarily mounted for the purpose. For work on a smaller scale, or in the preparation of very elaborate designs, other means may be employed.

For purely decorative purposes the miniature lamps serve a very useful purpose. Regular incandescents are made down to 6, 4, or even 2 candle power, but, as has already been explained, the filaments for these powers at ordinary voltages must needs be very slender and fragile, and the lamps are somewhat bulky.

Hence for many uses it is better to make miniature lamps for connection in series, each lamp taking 5 to 25 volts to bring it to normal candle power. Imagine a 16-c.p. 100-volt lamp filament cut into four equal parts, and each of these parts mounted in a separate small bulb, and you have a clear idea of the principle involved. Commonly the miniature lamps for circuits of 100 to 125 volts are of 5 or 6 candle power, and connected five or even ten in series across the ordinary lighting mains. Fig. 171 gives an excellent idea of the size and appearance of the perfectly plain miniature lamp. It is fitted to a tiny socket of the same general construction as the standard sockets for ordinary lamps, but taking up so little room that the lamps can conveniently be assembled in almost any desired form.



Fig. 171. — Miniature Incandescent Lamp.

It is not altogether easy to manufacture these lamps so as to attain the uniformity necessary, if the lamps are to be run in series, and this at present constitutes a serious obstacle to their use on a large scale. They are generally not of high efficiency, since great uniformity and good life are the qualities most important.

They can be fitted with tiny ornamental shades, and may be obtained of various shapes and colors, so that very elaborate

decorative designs can be built up of them. In indoor work colored lamps may be freely used, and are capable of producing some very beautiful effects, but the plain or ordinary frosted lamps are most generally used.

Owing to the small size of the sockets and fittings, the miniature lamps can be packed so closely as to produce the effect of an almost uniform line of light at comparatively small distances, so that most ornate schemes of ornamental illumination can be carried out by their aid. They are also very useful in building up small illuminated signs. At present many small tungsten lamps with small bulbs in standard sockets are in use. They take commonly 5 to 10 watts at 10 volts or so, and are supplied in multiple from special transformers if worked on alternating current, or in series if worked on direct current.

Lamps of special sizes and shapes, from a tiny ½-c.p. bulb, hardly bigger than a large pea, to the candle-shaped lamp of 5 or 6 candle power, are sometimes used with good effect in interior decoration. When a regular electrical supply is not available, these little lamps can be obtained for very moderate voltages, say, from 5 to 10 volts, and can be run in parallel from storage cells, or even from primary batteries, for temporary use. All these miniature lamps can now be had with tantalum or with tungsten filaments which greatly improve the situation, especially if one has to work from batteries.

Such small lamps are sometimes used in the table decorations for banquets, and for kindred purposes. By their aid surprising and beautiful effects are attainable, which would be quite impossible with any flame illuminant. But they must be cautiously used, for their very facility tends to encourage their employment in effects more bizarre than artistic.

It is well, too, to add a word of caution as regards the possible danger from fire. It is so easy to wire for incandescents that, particularly when using miniature lamps, there is a natural tendency to rush the work at the expense of safety. Lamps in series on a 110-volt circuit are quite capable of dangerous results if anything goes wrong, and even the battery lamps are not absolutely safe in the presence of inflammable material.

It should, therefore, be an invariable rule not to install a temporary decorative circuit without the same attention to detail that would be exercised in a temporary circuit of the ordinary incandescents. The same precautions are not always necessary, but all

the wiring should be carefully done, joints should be fully protected, and, particularly, lamps should be kept out of contact with inflammable material.

The incandescent lamp is often commended as producing little heat, and, in fact, as compared with other illuminants, its heating power is small. But a vessel of water can be boiled by plunging an ordinary 16-c.p. lamp in it nearly up to the socket, and cloth wrapped about such a lamp will infallibly be ignited within a comparatively short time. The fact that the cloth does not burst into flame in a few minutes does not indicate safety, for time is an important element in ignition, and even an overheated steam pipe is capable of setting a fire, low as its temperature is. A good many fires have been started in shop windows by hanging fabrics too near to incandescent lamps, and even the miniature lamps are quite capable of similar mischief if in contact with anything easily inflamed. No illuminant has so high an efficiency that it produces a negligible amount of heat from the standpoint of fire risk.

Special cable is now made to which lights can be attached with great facility, and by this means temporary work may be quickly and safely done.

In ordinary domestic illumination miniature lamps have very little place. Nothing is to be saved by using them so long as they must be used in series at ordinary voltages. Now and then a 2- or 4-c.p. lamp may be useful as a night lamp, but it is better to use an ordinary lamp of moderate efficiency than to try miniature lamps. Sometimes, however, a circuit of miniature lamps may be installed for a dining room or a ballroom with excellent artistic results. In such cases it is better to use frosted than plain lamps, and, as a rule, colored lamps should be avoided, on account of the difficulty of getting delicate tints to show effectively.

Temporary decorative circuits may, however, be very useful in domestic illumination for fêtes and the like, in which case delicately colored ornamental shades can be applied or the lamps may be used in Japanese lanterns. Any country house fitted for electric lights can be temporarily wired for such purposes rather easily, and out-of-door temporary wiring can be installed without the rigid precautions necessary indoors.

In all decorative lighting it is important to recognize the fact that illumination is a means to an artistic end, and not of itself the primary object. One is, in these days of electric lighting, far more

likely to err by providing too much light than by failing to supply enough.

Great brilliancy is far less important than good distribution and freedom from glare. It is highly probable, for instance, that the effect of the illumination of the Electric Tower at the Pan-American Exposition would have been seriously injured by the substitution of 32-c.p. lamps for the 8-c.p. actually used, and it is absolutely certain that a dozen arc lights injudiciously placed would have detracted greatly from the harmonious result.

In interior illumination the same rule holds true. By the reckless use of brilliant radiants one can key the vision up to a point where its power of appreciating values in illumination is almost entirely lost. In decorative lighting great care must be used not to approach this point, but to leave the relief afforded by light and shade, and to realize the perspective in the details of the illumination.

The commonest cause of failure in proper illumination is thrusting a brilliant light between the spectator and the object to be viewed, with the inevitable result of losing detail and hurting the eyes. Brilliant diffused light is in this particular only less objectionable than direct light, and both should be assiduously avoided.

It must not be supposed that decorative lighting must necessarily be electric, since very beautiful results were attained before electric light was heard of, but electric lighting is unquestionably the most facile means of securing artistic results on a large scale.

CHAPTER XIV.

THE ILLUMINATION OF THE FUTURE.

At the present time the ordinary materials of illumination are pretty well understood, and their proper use is a matter of good judgment and artistic sense. Illumination is not an exact science with well-defined laws of what one might call illuminative engineering, but an art whereto an indefinable and incommunicable skill pertains almost as it does in the magic of the painter.

There are certain general rules to be followed, certain utilitarian ends which must be reached at all hazards, but whether the result is brilliantly successful or hopelessly commonplace depends on the skill that inspires it. There must be in effective illumination a constant adaptation of means to ends, and a fine appreciation of values that quite defies description. One may attack the problem of illuminating a great building with all the resources of electrical engineering at his command, and score a garish failure, or he may conceivably be confined to the meager bounds of lamps and candles, and still triumph.

The general tendency with the modern intense radiants at command is to light too brilliantly, to key the vision to so high a pitch that it fails to appreciate the values of the *chiaro-oscuro* on which the artistic result depends.

The desideratum in illumination, except for a small group of scenic effects, is the possession of cheap and fairly powerful radiants of low intrinsic brilliancy, capable of modification in delicate color tones. It is doubtful whether these qualities are compatible with very high luminous efficiency in a flame or incandescent radiant. In modern gas and electric lighting the progress toward efficiency is in the direction of very high temperature, which implies high intrinsic brilliancy.

Vacuum tube lamps give hope of better things, but at great risk of color difficulties, particularly if high efficiency is reached.

Ideally, a gaseous radiant, with nearly its whole luminous energy concentrated in the visible spectrum, would give magnificent efficiency, but it by no means follows that it would give a good

light. Sodium vapor meets the requirements just noted tolerably well, yet there is no more ghastly light than that given by a salted spirit lamp.

It might be possible to work with a mixture of gases such as would give a light approximately white to the eye, and yet be very far from a practicable illuminant; for the phenomena of selective absorption are such, as we have already seen, that the color of a delicately tinted fabric depends on its receiving a certain scale of colors in the light which it reflects. To the eye a much simpler color scheme is competent to reproduce light substantially white, and such light falling on a colored fabric would by no means necessarily bring out the tints that glow by daylight.

Even the firefly's secret, could man once penetrate it, might not prove such a valuable acquisition as it would seem at first thought. To the eye the light of most species seems greenish, and, in point of fact, it so completely lacks the full red and the violet rays that its effect as an illuminant on a large scale would be rather unpleasant, far worse than an early Welsbach at its most evil stage of decrepitude. We must not only steal the firefly's secret, but give him a few useful hints on the theory of color before the net result will be satisfactory from the æsthetic standpoint. Firefly light might do for a factory, but it would find but a poor market as a household illuminant.

It is a somewhat difficult matter satisfactorily to define the efficiency of an illuminant. Luminosity depends, like sound, upon the physiological relations of a certain form of energy, and cannot be directly reduced to a mechanical equivalent.

The commonest conception of the efficiency of an illuminant is to regard it as defined by the proportion of the total radiant energy which is of luminous wave lengths. From this point of view the efficiency may approach unity either by the absence of infra-red and ultra-violet rays, — in other words, by purely selective radiation, — or by so great an increase of radiation in the visible spectrum as to render the energy of the remainder nearly negligible.

In the former sense the luminous radiation of the firefly is of perfect efficiency; but, obviously, a purely monochromatic light utilizing the same total amount of energy might give a vastly better illumination — or a much worse one, according to the wave length of the light in relation to its effect on the eye.

On the other hand, an intensive arc between tiny pencils of the material used for Nernst glowers is reputed to give, so far as watts per candle power go, an efficiency nearly as good as can be claimed for the firefly. The experiments in this case are perhaps not beyond cavil, but, even granting their substantial accuracy, it is perfectly certain that such an arc gives radiation by no means confined to the visible spectrum.

The most that can be said in a definite way is that, assuming a continuous spectrum with its maximum luminous intensity in the yellow or yellowish green, there seems to be little chance of doing much better than about 0.2 watt per candle power.

As a matter of fact, this efficiency is not approached by any practical illuminant giving a continuous spectrum. It has been reached and passed by some of the yellow-flame arcs burning carbons charged with calcium fluoride, of which the spectrum has its most intense bands in the region near to the highest point in the luminosity curve of the human eye. Of lights giving an approximately white light, the most efficient is the flame arc using carbons impregnated with ceria and some similar substances, by-products of the Welsbach industry, which closely approaches but does not quite equal the figures just given for the yellow-flaming arc. The white arc loses somewhat from the fact that it is white, and consequently to secure this color must contain rays of lower specific luminosity than those of the calcium-fluoride arc. The luminous arcs charged with iron and titanium can be pushed to somewhere between 0.5 and 0.75 watt per mean spherical candle power, and the most efficient of the open-carbon arcs may closely approach the latter figure. Carbon incandescent lamps scarcely do better than 3 to 4 watts per mean spherical candle power, and even the tungsten and other metallic filament lamps more recently introduced show a specific consumption not better than 1.5 watts per mean spherical candle power.

Lamps employing incandescent gas or vapor vary over a considerable range, according to the spectral characteristics of the light and other properties of gas or vapor involved. The specific consumption of the intensive mercury arcs is approximately the same as that of the white flame arcs, that is, 0.25 to 0.3 watt per candle, the ordinary mercury arcs having a specific consumption of about twice this figure. Were all the energy concentrated in the green mercury line a startling improvement would be made,

since the luminous efficiency actually found for this line exceeds 50 candles per watt.

The Moore tube, worked far less intensively than the mercury arcs, scarcely reaches a specific consumption of 2 watts per candle with the gases ordinarily available, while the white CO_2 tube of this type operates at 6 or 8 watts per candle, the CO_2 unfortunately giving much radiation of very low or totally negligible luminous value. Tubes filled with neon work at somewhat better than 1 watt per candle power but the gas is costly and troublesome to work with. Thus, in spite of the improvements in illuminants during recent years, there is still much to be done in improving their efficiency, and especially in the smaller units. All the very high efficiencies yet attained have been with radiant sources of several hundred or even several thousand candle power.

For everyday work the thing most needed is an efficient light of moderate candle power and moderate intrinsic brilliancy combined with low cost and good color. Save under special circumstances, very powerful radiants are disadvantageous, particularly if of great intrinsic brilliancy.

Casting about the field, it certainly appears at first glance as though most modern radiants had been developed in the wrong direction. In particular, electric lights have been steadily pushed in the direction of enormous working temperature and very great intrinsic brilliancy, gaining greatly in efficiency, of course, but losing in convenience. What is most wanted is not a light giving 5000 candle power at 0.2 watt per candle, but one for ordinary voltages giving 5 or 10 candle power at even 1 watt per candle. The vacuum-tube lamp seems at present to give the greatest chance for revolutionary improvements, and even this seems to involve very serious difficulties.

Similarly, in gaslights we have regenerative and mantle burners giving 50 or 100 candle power at a very good efficiency or press-gas burners of 1000 or more candle power at still very much higher efficiency, but they are too powerful and too bright to be entirely satisfactory, even were they open to no other objections. For most purposes, a Welsbach giving 15 candle power on 1 cubic foot of gas per hour would be vastly more useful than one giving 75 candle power on 4 cubic feet per hour. Of flame radiants, none save acetylene marks any material advance in recent years in point of easy applicability. It would seem that modern chemistry might

achieve something of value in adding to the materials of illumination. There is a group of substances possessing enormous power of giving off radiation when suitably stimulated. It is perhaps not too much to hope that some such material of extraordinary potency with respect to luminous rays may reward the pertinacious investigator. There is no intrinsic reason why an exaggerated type of phosphorescence, capable of storing sunlight at a high efficiency, may not in due season be discovered. This would settle the artificial lighting problem — unless the color were irremediably bad — in a beautifully simple way. Or it might be possible to reproduce by a commercial process the slow oxidation or analogous change responsible for the glowing of decaying wood and of certain microörganisms, and probably also for the light of the firefly and his allies.

Whatever the method, the aim of improvement should be the production of efficient lights of moderate intensity and intrinsic brilliancy, coupled with good color, preferably capable of easy modification.

The steady tendency, as the art of illumination has advanced, has been towards more and more complete subdivision of the radiants, and the subordination of great brilliancy to perfect distribution. One of the most important lessons of the Pan-American Exposition was Mr. Stieringer's demonstration of the magnificent usefulness of 8-c.p. incandescent lamps, skillfully installed.

In the art of illumination, as much depends on the efficient use of lights as on the efficiency of the lights themselves. A tallow candle, just where it ought to be, is better than a misplaced arc lamp, and, even taking our present illuminants with all their limitations, skill will work wonders of economy.

It is particularly in the direction of adroit use that the present path of progress lies. One of the fundamental facts in practical lighting, which has been many times suggested in these pages, and which lies at the root of improvements, is the need of keeping down intrinsic brilliancy.

The true criterion of effective and efficient lighting is not simple illumination, which resolves itself into a pure matter of foot-candles, but *visual usefulness*, which takes account of the physiological factors in artificial lighting.

If one denotes the illumination measured in foot-candles or other convenient units by I, then the *visual usefulness* is in part meas-

ured by the product $I\sigma$, where σ is proportional to the effective area of the pupil. This of course is constantly shifting as the illumination changes, but, broadly, it is an inverse function of the intrinsic brilliancy of the radiants used. Other physiological factors like adaptation also depend directly upon the intrinsic brilliancy to which the retina is exposed. The criterion thus becomes of the form $i = \frac{I}{f(B)}$, where B is the intrinsic brilliancy of the radiant, and i is the visual usefulness, or the effective brilliancy of the illumination.

Now as a matter of practice this is important, for it indicates that a badly placed arc light, for example, may actually work serious injury to the effective illumination, and within reasonable limits one could fairly go as far as to say that the usefulness of an unmodified radiant varies inversely with its intrinsic brilliancy. Obviously, then, shading the radiant may gain useful illumination, although it actually loses light, which in fact experience has shown to be the case.

In electric lighting, incandescent lamps at 3 watts per candle, so disposed as to keep clear of the field of vision, are fully as valuable illuminants as lamps at 2 watts per candle wrongly installed, so as to either dazzle the eye or to require heavy shading to avoid it. Shaded they must be for hygienic reasons whenever visible.

In actual practice it is a matter of great difficulty to place lights wholly out of the field of vision, and the more brilliant the lights are the greater necessity for shading them. Hence, it becomes a difficult matter to treat modern illuminants without loss of efficiency.

A very promising line of improvement in artificial lighting, and the one from which much may be expected in the near future, is indirect and semi-indirect lighting. As the intrinsic brilliancy of the source rises, the relative importance of diffusion increases, since shading, to be effective, must be denser.

There is room for splendid developments in diffuse lighting, using arcs, Nernst lamps, incandescents of every sort, Welsbach mantles, and acetylene. In this way such radiants can be used with the full advantage of their great efficiency, and with good diffusion from white or nearly white surfaces the net efficiency can be fairly well maintained. As has already been noted, lighting by diffusion in ordinary interiors, where the surfaces are not generally good, requires a very lavish use of light, but with a careful

study of the conditions may come the possibility of efficient and beautiful lighting in which the radiants shall be effectively concealed.

This method of working, too, has an artistic advantage, in that the light can be slightly modified by tinted diffusing surfaces with far greater success than by any arrangement of colored shades. The latter are not available in delicate and easily graduated shades, while pigments can be worked upon diffusing surfaces in almost any desired manner.

The weak point of lighting by diffusion is the fact that the radiants are usually installed in rather inaccessible places, and the reflectors are certain to suffer from dust, unless special care is taken.

It will be readily seen that the attainment of high luminous efficiency by means of driving illuminants to a very high specific brilliancy tends to defeat its own ends. If it costs, as it does, from 20 to 40 per cent of the luminous energy to secure diffusion complete enough to render the source suitable to use, then it is clear that it may be worth while to sacrifice a corresponding amount in luminous efficiency, in order to obtain a light of sufficiently low intrinsic brilliancy to be used without diffusion.

Just how low intrinsic brilliancy is necessary to render the use of diffusers needless depends in no small measure on the amount of luminous energy which reaches the eye from the source considered. In other words, the physiological danger of glare from an illuminant is a function of the rate at which the retina has to take care of the energy which is delivered to it. Destructive and constructive work is continually being done at the retina, and the net result depends on the balance between these two factors. Neglect of this question of energy has led to a great deal of unnecessary alarm and trouble.

As a matter of common experience, an arc light in a thin diffusing globe, of which the intrinsic brilliancy is conspicuously greater than could be tolerated at short range, is perfectly harmless at the distance of a few hundred feet, while a source of considerably lower intrinsic brilliancy might be painful and harmful at close range. When the eye is in a state of full dark-adaptation, even very weak sources may produce harmful glare. The author has suffered from the misquotation of a paragraph in the first edition of this book, which set about 5 candle power per square inch as the highest permissible intrinsic brilliancy, although in

the same paragraph he stated that half this value was preferable. Five candle power per square inch is perfectly safe out of doors or in large spaces, while even 2.5 may be excessive in lights at short range. In ordinary interior work it is preferable to keep the intrinsic brilliancies well below this figure, in extreme cases perhaps even below 1 candle power per square inch.

Now, no unscreened illuminant, save the Moore tube, falls within this particular region, and it is to vacuum-tube or luminescent lighting in one form or another that we chiefly must look for sources of intrinsic brilliancy low enough to permit them to be used unscreened. It seems doubtful at present whether they can be obtained at an efficiency which makes the game worth the candle. Considering the low intrinsic brilliancy of the Moore tube, however, it compares more favorably with necessarily screened sources of light than its actual specific consumption in watts per candle would indicate.

Aside from gaseous illuminants, the best chance for obtaining sources of low intrinsic brilliancy seems to be by chemical processes analogous to those carried on by photogenic bacteria and perhaps by the fireflies. Nothing practical has yet appeared in this particular field. Certain luminescent phenomena akin to phosphorescence have been the subject of some experiments, and are not without hope for useful results, although nothing substantial has yet been done.

Broadly, then, future progress in efficient illumination depends either upon further increase in the luminous efficiency of intense sources, or, on the other hand, in the development of fairly efficient, less intense sources which make up by low intrinsic brilliancy for their losses in specific consumption. Improvements of the first sort have been rapid since the first edition of this book was published, and have now reached, as the figures given earlier indicate, a point where further progress is likely to be slow. The improvements in the near future are likely to be rather in length of life and steadiness of the luminous sources than in any conspicuous increase of efficiency. Along the second line of progress there is perhaps a greater opportunity, albeit we do not know in what particular way it is likely to be brought to our notice.

Meanwhile we must do the best we can, with the illuminants which are now at hand, to furnish light of suitable amount and quality. To sum up the suggestions repeatedly made in these

pages, the commonest failings in present methods of lighting are a tendency to use too brilliant radiants and to make up in quantity what is lacking in quality. More study of the practical conditions of lighting and less blind faith in bright lights would generally both improve practical illumination and tend to economy.

Imagine, for example, an attempt to light a billiard table where the balls had been stained to match the cloth. Yet this sort of thing, on a less aggravated scale, happens far oftener than would be thought possible. Even in buildings designed to fulfill hygienic conditions, sins against the fundamental principles of lighting are distressingly common. An observing writer has grimly designated modern schools "bad-eye factories," and certainly, even with the full advantage of natural light and buildings in which conditions ought to be favorable, the results are frequently bad.

With artificial light the task of proper lighting is of increased difficulty, and is further complicated by the sometimes impossible requirements of the latest fashionable scheme of decoration. The best results can be attained only by constant attention to details and a keen perception of the conditions to be met.

The illumination of the future ought to mean the intelligent use of the lights we now have, not less than the application of the lights which we may hope in the fullness of time to obtain.

INDEX

A.

Abney's table of color differences, 28.
Abolition of shadows, 19.
Acetylene burner, 94.
Acetylene gas, 91.
Acetylene gas, cost of, 97.
Adaptation of the eye, 6.
Adoption of international standard candle, 58.
After-images in the eye, 13.
Air gas, 85.
Air vitiation of various illuminants, 115.
Altar illumination, 256.
Alternating- and direct-current arc lights, comparison of, 162.
Alternating-current arc light, 159.
Alt-market, Dresden, 288.
Analysis of coal gas, 87.
Apparatus for comparison of incandescent lights, 67–69.
Arc lamp, Blondel's flaming, 168.
Arc light, alternating-current, 159.
Arc light carbons, 153, 155.
Arc light, comparison of direct- and alternating-current, 162.
Arc light, current density and intensity, 152.
Arc light, efficiency of, 158.
Arc light, flaming, 164.
Arc light, flaming, General Electric Company's, 170.
Arc light, inclosed, distribution of light from, 157.
Arc light, intensive, 163.
Arc light, inverted, 274.
Arc light, Jandus regenerating flame arc, 169.
Arc light, luminous, 172.
Arc light, magnetite, 172.
Arc light, open, distribution of light from, 156.
Arc lights, color of, 164.
Arc lights, efficiencies of, 162.
Arc lights in work shops, 247.
Arc lights, open, 153.
Arc lights, outdoor, 156.
Arcs, magnetic, 312.
Arcs, vertical carbon flame, 312.
Argand gas burner, 89.
Arrangement of interior lights, 213.
Artificial light, early sources of, 77.
Artificial lighting, fundamentals of, 11.
Auer light, 101.

B.

Basements, illumination of, 231.
Basic facts in incandescent lamp practice, 122.
Bathrooms, illumination of, 231.
Bedrooms, illumination of, 230.
Berlin high pressure gas plant, 109.
Billiard rooms, illumination of, 231.
Blackboards, lighting of, 265.
Blau-gas, 88.
Blondel system lamps, 312.
Blondel's flaming arc lamp, 168.
Boston schoolroom illumination, 262.
Bouguer's photometer, 60.
Brackets, use of, in interior lighting, 222.
Bunsen burner, 103.
Bunsen screen, 61.
Bunsen photometer, 60–62.
Burner, acetylene, 94.
Burner, Bunsen, 103.
Burner, oxyhydrogen, 100.
Burning fluids of early days, 80.

C.

Candle, foot, definition of, 7.
Candle, international standard, 57.
Candle, meter, definition of, 7.
Candle, parliamentary sperm, 53.
Candles, illuminating, 81.
Calcic carbide, 92.
Carcel lamp, 53.
Carbons, arc light, 153, 155.
Ceiling lights, 217.
Ceiling lights in halls, 238.
Cellulose mantles, 110.
Ceria, action of, in Welsbach mantles, 102.
Ceria and color variation in mantles, 113.
Chandeliers, 223.
Chandeliers, for churches, 253.
Chevreul's experiments with tinted lights, 34.
Church altar lighting, 256.
Church chandeliers, 253.
Churches, illumination of, 252.
Classes of illuminants, 77.
Clerical work, illumination for, 234.
Closets, illumination of, 231.
Coal gas, 86.
Color absorption, 29.
Color differences, Abney's table of, 28.
Color, fundamental law of, 25.
Color of arc lights, 164.
Color of incandescent electric lamps, 129.
Color of mantle burners, 112.
Color of walls in practical illumination, 51.
Colored glass, luminosity of light through, 32.
Colored illumination, 324.
Colored lights, effects of, on colors, 29.
Colored lights, general effects of, 33.
Colors, effects of faint illumination on, 30.
Colors of common illuminants, 35.
Colors of the solar spectrum, 26.
Colors, variation of, under artificial light, 27.
Colors viewed in colored lights, 29.
Commercial candles, 82.
Common troubles of mantle burners, 114.
Comparing incandescent lights, 67.
Composition of petroleum, 80.
Composition of Welsbach mantle, 101.
Construction of the incandescent electric lamp, 119.
Construction of Nernst lamp glower, 146.
Consumption of gas in inverted burners, 107.
Consumption of gas in open and mantle burners, 105.
Consumption of incandescent lamps, 136.
Contracts for street lighting, 314.
Converging carbon lamps, 312.
Cooper-Hewitt mercury vapor lamp, 177.
Copley Square, Boston, 288.
Cost of manufacturing acetylene gas, 97.
Cost of various illuminants, 115.
Cotton mantles, 110.
Counting room illumination, 241.
Current density and intensity in arc light, 152.
Cut glass shades, 184.

D.

D'Arsonval acetylene gas generator, 94.
Davy introduces electric arc, 150.
Daylight photometer, 21.
Decorative circuits, temporary, 334.
Decorative fixtures, 224.
Decorative illumination, 316–335.
Delivery rooms, illumination of, 269.
Determining amount of illumination necessary, 4.
Development of the incandescent lamp, 100.
Diffuse reflection, 38.
Diffuse reflection from colored papers, 49.

Diffusion in interior illumination, 210.
Dining rooms, illumination of, 228.
Direct- and alternating-current arc lights, comparison of, 162.
Direct-indirect reflectors, 206.
Direct vs. indirect system for offices, 242.
Disk, the Leeson, 62.
Distribution of artificial light affecting the eye, 15.
Distribution of interior lights, 215.
Distribution of light from an open arc, 156.
Distribution of light from inclosed arc light, 157.
Distribution of street light, 302.
Dressing tables, illumination of, 230.
Drummond light, 99.
Domes, illumination of, 251.
Domestic lighting, 207–232.
Domestic lighting, important rule for, 220.

E.

Earliest sources of artificial light, 77.
Economics of the incandescent lamp, 132.
Economy in street lighting, 298.
Efficiencies of arc lights, 162.
Efficiencies of utilization, 245.
Efficiency, 338.
Efficiency and temperature in incandescent lamps, 128.
Efficiency in incandescent electric lamps, 130.
Efficiency of commercial incandescent lamps, 126.
Efficiency of electric arc light, 158.
Electric arc light, principle of, 150.
Elliot lamp, 59.
English schoolroom lighting, 265.
Exposition buildings, 277.
Extensive reflectors, 199.
Exterior illumination, 279–315.
Eye, human, and light, 2, 5, 6, 13.
Eye, human, iris diaphragm, 13.
Eye, human, variation of pupil, 14.

F.

Fabrics, reflection from, 46–48.
Façade illumination, 320.
Factors in interior illumination, 209.
Faint illumination, effect of, on colors, 30.
Fechner's fraction, 4.
Fechner's law, 3.
Filaments, first attempts, 116.
Filaments, forms of, 120, 121.
Filaments, looped, 124.
Filaments, manufacture of, 117.
Filaments, metallized, 136.
Filaments, osmium, 136.
Filaments, tantalum, 137.
Filaments, tungsten, 138.
First-class streets, lighting, 296.
First public street lighting, 291.
Fixtures, decorative, 224.
Flame illuminants, 79.
Flaming arc light, 164.
Flat-flame gas burners, 89.
Flicker photometer, 64.
Flickering lights, 16, 17.
Flux in street lighting, 305.
Flux of light method of computation, 246.
Flux, luminous, unit of, 10.
Foot-candle, definition of, 7.
Fraction, Fechner's, 4.
Fraunhofer lines, 26.
Frieze illumination, 250.
Frieze lights in halls, 238.
Fundamental law of color, 25.
Fundamentals of artificial lighting, 11.

G.

Gas, acetylene, 91.
Gas, acetylene, cost of, 97.
Gas, air, 85.
Gas burner, Argand, 89.
Gas burner, flat-flame, 89.
Gas burner, Siemens regenerative, 90.
Gas burner, Wenham, 90.
Gas burners, 88.
Gas, coal, 86.
Gas consumption in open and mantle burners, 105.

Gas lights, high pressure, 107.
Gas lights in shops, 248.
Gas machines, 85.
Gas, Pintsch, 88.
Gas, water, 87.
Gasoline gas machine, 85.
General Electric Company's flame-arc lamp, 170.
General illumination and reflection, 46.
Generators, acetylene, 94–95.
Glass, colored luminosity of light transmitted through, 32.
Glass shades, 187.
Globe, holophane, 191.
Globes, light absorption of various kinds, 186.
Goggles, Indian, 2.
Grouping lights in illumination of halls, 237.

H.

Hallways, illumination of, 225.
Halls, illumination of, 236.
Harcourt pentane standard, 54.
Hefner lamp, 53, 54.
Height of street lights, 303.
Heterochromic photometry, 66.
Hewitt's fluorescent reflecting screen, 179.
High pressure gas lights, 107.
High room illumination, 219, 249.
Holophane globes, 191.
Houston and Kennelly's illuminometer, 74.
Human eye, the, 2, 5, 6, 13.
Hygienic relations of illuminants, 114.

I.

Illuminants, acetylene gas, 91–94.
Illuminants, common, colors of, 35.
Illuminants, comparative cost of, 115.
Illuminants, composition of, 77.
Illuminants, flame, 79.
Illuminants, hygienic relations of, 114.
Illuminants, interior, choice of, 215.
Illuminants, petroleum, 80.
Illuminants, street, modern varieties, 312.
Illuminating gases, 87.
Illuminating system in Boston schoolrooms, 263.
Illumination, artificial, key to, 3.
Illumination for high rooms, 219.
Illumination for machines, 244.
Illumination for public buildings, 258.
Illumination for work rooms, 243.
Illumination, indirect, 203.
Illumination of basements, 231.
Illumination of bathrooms, 231.
Illumination of bedrooms, 230.
Illumination of billiard rooms, 231.
Illumination of churches, 252.
Illumination of closets, 231.
Illumination of dining rooms, 228.
Illumination of domes, 251.
Illumination of halls, 236.
Illumination of hallways, 225.
Illumination of kitchens, 229.
Illumination of large rooms, 235–278.
Illumination of libraries, 227.
Illumination of library buildings, 267.
Illumination of living-rooms, 228.
Illumination of music rooms, 226.
Illumination of offices, 233.
Illumination of pantries, 229.
Illumination of public rooms, 269.
Illumination of public squares, 281.
Illumination of reception rooms, 226.
Illumination of schoolhouses, 261.
Illumination of shops, 247.
Illumination of tennis courts, 265.
Illumination of the Mosque of St. Sophia, 255.
Illumination of theaters, 259.
Illumination, strength of, in relation, to shade perception, 5.
Illumination, strength of, required for, various needs, 20.
Illumination, to determine amount necessary, 4.
Illumination, two general purposes of, 1.

Illuminometer, Houston and Kennelly's, 74.
Incandescent electric illumination, basic facts, 122.
Incandescent illuminants, 99.
Incandescent electric lamps, 116–149.
Incandescent electric lamps, color of, 129.
Incandescent electric lamps, consumption of, 136.
Incandescent electric lamps, efficiency of, 126, 130.
Incandescent electric lamps, sizes of, 129.
Incandescent electric lamp, economics of, 132.
Incandescent electric lamps, measuring, 123.
Incandescent lamps, photometering, 67.
Inclosed arc light, principle of, 153.
Indian goggles, 2.
Indirect illumination, 203.
Indirect illumination in large interiors, 275.
Indirect lighting for offices, 242.
Indirect vs. direct system for offices, 242.
Intensive arc light, 163.
Intensive reflectors, 199.
Interior decorating, 331.
Interior illuminants, choice of, 215.
Interior illumination, factors in, 209.
Interior illumination, diffusion in, 210.
Interior lights, arrangement of, 213.
Interior lights, distribution of, 215.
International standard candle, 57.
Intrinsic brightness, definition of, 11.
Inverted arc light, 273.
Inverted mantle burners, 105.
Inverted reflectors, 205.
Iris, action of, in various lights, 15.
Iris diaphragm of the eye, 13.

J.

Jandus regenerating flame lamp, 169.
Junior Welsbach light, 104.

K.

Kerosene lamps, 83.
Key to artificial illumination, 3.
Kitchens, illumination of, 229.

L.

Lamp, Blondel flaming arc, 168.
Lamp, Carcel, 53.
Lamp, Cooper-Hewitt mercury vapor, 177.
Lamp, Elliot, 59.
Lamp, flaming arc, mechanism of, 166.
Lamp, General Electric Company's flame-arc, 170.
Lamp, Hefner, 53, 54.
Lamp, incandescent, development of, 100.
Lamp, Jandus regenerating flame arc, 169.
Lamp, magnetic, 313.
Lamp, magnetite arc, 172.
Lamp, Nernst, 144.
Lamps, osmium, 136.
Lamp, quartz-mercury, 179.
Lamp, tantalum, 137.
Lamp, titanium-carbide arc, 176.
Lamps, tungsten, 140.
Lamps, converging carbon, 312.
Lamps, earliest patterns, 78.
Lamps for outlining, 330.
Lamps, incandescent, photometering, 67.
Lamps, magnetic arc, 312.
Lamps, miniature, 332.
Lamps, oil, 82.
Lamps, Rochester, 83.
Lamps, street, location of, 308.
Lamps, system, Blondel, 312.
Large rooms, illumination of, 235.
Law, Fechner's, 3.
Law, fundamental, of color, 25.
Law of inverse squares, 8.
Law of regular reflection, 37.
Leeson disk, 62.
Libraries, illumination of, 227.
Library buildings, illumination of, 267.

Library stacks, lighting, 269.
Life of mantles, 111.
Light absorption of various globes, 186.
Light and the eye, 10–24.
Light, arc, alternating-current, 159.
Light, artificial, early sources of, 77.
Light, flaming arc, 164.
Light, inclosed arc, distribution of light from, 157.
Light, intensive arc, 163.
Light, luminosity of, 32.
Light, luminous arc, 172.
Light, magnetite arc, 172.
Light measurement, questions involved, 52.
Light, open arc, distribution of light from, 156.
Light, quartz-mercury, 180.
Light, the Moore tube, 181.
Light, Welsbach, 101.
Lighting by inverted arcs, 273.
Lighting, direct-indirect, 206.
Lighting, domestic, important rule for, 220.
Lighting, domestic, 207–232.
Lighting high rooms, 249.
Lighting, indirect, 205.
Lighting schoolrooms, 263.
Lighting, spotted, remedy for, 243.
Lighting tennis courts, 265.
Lights, arc, 150–183.
Lights, ceiling, 217.
Lights for signals, 32.
Lights, interior, arrangement of, 213.
Lights, open arc, 153.
Lights, side-wall, 218.
Lime lights, 99.
Living rooms, illumination of, 228.
Location of ceiling lights, 217.
Location of street lamps, 308.
Looped filaments, 124.
Lucigen torch, 84.
Lumen, definition of, 10.
Luminous arc light, 172.
Luminous flux, unit of, 10.
Lummer-Brodhun photometer, 60, 63.
Lux, as a unit of illumination, 10.

M.

McCreary shade, 189.
Machine illumination, 244.
Magnetic arc lamps, 312.
Magnetite arc light, 172.
Malignani process of exhausting bulbs, 120.
Mantle burners, 103–106.
Mantle burners, color of, 112.
Mantle manufacture, materials used, 110.
Mantles, color variation in, 113.
Mantles, common troubles, 114.
Mantles, cotton, 110.
Mantles, life of, 111.
Mantles, silk, 110.
Mantles, Welsbach, composition of, 101.
Manufacture of filaments, 117, 121.
Manufacturing cost of acetylene gas, 97.
Material in mantle manufacture, 110.
Matthew's integrating photometer, 70.
Measurement of light, questions involved, 52.
Measuring daylight, 21.
Measuring incandescent lamps, 123.
Measuring intrinsic brightness, 12.
Measuring street illumination, 310.
Mechanism of flaming arc lamps, 166.
Mercury vapor lamp, 177.
Metallic oxide lamps, 313.
Metallized filaments, 136.
Meter-candle, definition of, 7.
Methods of determining unit of illumination, 10.
Methods of interior illumination, 208.
Methods of lighting halls, 238–240.
Methven screen, 59.
Miniature incandescent lamps, 332.
Moonlight schedules, 299.
Moore tube, 181, 339.
Mosque of St. Sophia, lighting of, 255.
Multiple-looped filaments, 126.
Multiple reflection, 43.

Museums, lighting, 271.
Music rooms, illumination of, 226.

N.

Nernst lamp, 144.

O.

Offices, illumination of, 233.
Oil lamps, 82.
Osmium filaments, 136.
Outdoor arc lights, 156.
Outlets for hall illumination, 240.
Outlets in interior illumination, 222.
Outlining illumination, 325.
Oxides in magnetite arc lamps, 176.

P.

Pantries, illumination of, 229.
Paper, colored, reflective qualities, 49.
Park lighting, 280, 289.
Parliamentary sperm candle, 53.
Pentane standard, 54.
Periodical rooms, illumination of, 270.
Petroleum as an illuminant, 80.
Petroleum products, 81.
Photometer, daylight, 21.
Photometer, Matthews' integrating, 70.
Photometer, portable, 71–74.
Photometers, the Bouguer, 60.
Photometer, the Bunsen, 60–62.
Photometer, the "flicker," 64.
Photometer, the Lummer-Brodhun, 60, 63.
Photometer, the reading, 75.
Photometer, the Simmance-Abady, 65.
Photometering incandescent lamps, 67.
Photometrical standards, 53.
Photometry, 59.
Photometry, heterochromic, 66.
Pintsch gas, 88.
Place de la Concorde, illumination of, 281.
Platinum in electric lamp, 119.
Point-to-point method, 70.
Portable lights, acetylene, 96.
Portable lights, Lucigen torch, 84.
Portable photometer, 71–74.
Portable photometer, Weber's, 70–72.
Potsdamer Platz, Berlin, 282.
Press-gas lighting, 109.
Principle of the arc light, 150.
Principle of the inclosed arc light, 153.
Prismatic reflectors, 196.
Products of petroleum, 81.
Public building illumination, 258.
Public rooms, illumination of, 269.
Public squares, 280.
Pupil of the eye, variation of, 14.

Q.

Quartz-mercury lamp, 179.
Quai de Mt. Blanc, 317.

R.

Radiants for street lighting, 303.
Railway stations, 272.
Ramie fiber mantles, 110.
Rare earths in Welsbach mantles, 101.
Reading lamps, 223.
Reading photometer, 75.
Receptacles for decorative designs, 330.
Reception rooms, illumination of, 226.
Reflected spectra, 26
Reflecting cove, 203.
Reflecting shades, 188.
Reflecting surfaces, table of results from, 45.
Reflection, diffuse, 38.
Reflection, diffuse, from various surfaces, 49, 50.
Reflection from fabrics, 46–48.
Reflection from colored papers, 49.
Reflection in general illumination, 46.
Reflection, multiple, 43.
Reflection, regular or specular, 37.
Reflection, selective, 36, 42.
Reflection, Trotter's experiments in, 41.
Reflectors, cove, 203.
Reflectors, extensive, 199.
Reflectors, intensive, 199.

Reflectors, inverted, 205.
Reflectors, prismatic, 196.
Reflectors, X-ray, 205.
Regenerative gas burners, 90.
Remedy for spotted lighting, 243.
Rochester lamp, 83.
Roman lamps, 78.
Rule for domestic lighting, 220.

S.

Scenic illumination, 316–335.
Schoolhouses, lighting of, 261.
Schoolrooms in England, method of lighting, 265.
Schoolrooms in Boston, method of lighting, 264.
Screen, Hewitt's fluorescent reflecting, 179.
Screening street lamps, 310.
Search lights for surface lighting, 320.
Second-class streets, lighting, 297.
Selection of interior illuminants, 215.
Selective reflection, 36, 42.
Series magnetite lamp, 174.
Shades, objectionable, 185.
Shade perception, 5.
Shade, the McCreary, 189.
Shades and reflectors, 184–206.
Shadows, abolition of, 19.
Shops, illumination of, 247.
Shotgun diagrams, 133.
Side lights, 218.
Siemens regenerative burner, 90.
Signals, lights for, 32
Silk mantles, 110.
Simmance-Abady photometer, 65.
Sizes of incandescent electric lamps. 129.
Snow blindness, 2.
Solar spectrum, 26.
Sources, earliest, of artificial light, 77.
Spacing of street lights, 303.
Special reflectors, 203.
Spectra, reflected, 27.
Specular reflection, 37.
Spot light for surface illumination, 322.
Spotted lighting, remedy for, 243.
Standard, the pentane, 54.
Standard, Violle's platinum, 57.
Street decorating, 328.
Street illuminants, 312.
Street illumination, measuring, 310.
Street lamps, height of, 307.
Street lamp, screening, 310.
Street lighting, 290.
Street lighting, contracts for, 314.
Street lighting, distribution of, 302.
Strength of illumination required for various work, 20.
Structural illumination, 318.
Structural limitations in interior lighting, 216.
Surface illumination, 319.
Switches for interior lighting, 232.
System Blondel lamps, 312.

T.

Table, Abney's, of color differences, 28.
Table, Chevreul's experiments with tinted lights, 34.
Table, comparison of direct- and alternating-current arcs, 162.
Table of intrinsic brilliancies in candle power per square inch, 12.
Table of Nernst lamp data, 148.
Table, petroleum products, 81.
Table, relations between various primary standards, 58.
Table, results from various reflecting surfaces, 45.
Tantalum lamp, 137.
Temperature and incandescent lamp efficiency, 128.
Temporary decorative circuits, 334.
Temporary illumination, 272.
Tennis courts, illumination of, 265.
Thames Embankment, 317.
Theater illumination, 259.
Theory of the Ulbricht sphere, 70.
Third-class streets, lighting, 297.
Titanium-carbide arc lamp, 176.
Torch, Lucigen, 84.
Trafalgar square, illumination of, 281.
Trotter's experiments in reflection, 41.

Tungsten filament, 138.
Tungsten lamps, 140.
Tungsten lamps in parks, 290.
Tungsten lamp in domestic lighting, 221.
Tungsten street lamp, 314.

U.

Ulbricht sphere, 70.
Unilateral illumination, 275.
Units of illumination, 10.
Utilization, efficiencies of, 245.

V.

Vacuum tube lamps, 336.
Variation in commercial incandescent lamps, 134, 135.
Variation of color in mantles, 113.
Variation of colors under artificial light, 27.
Variation of "law of inverse squares," 9.
Variation of the pupil of the eye, 14.
Vertical carbon flame arcs, 312.
Violle's platinum standard, 57.
Visual usefulness, 340.
Vitiation of air by various illuminants, 115.

W.

Water gas, 87.
Weber's portable photometer, 70–72.
Weber's tests of incandescent lamp efficiency, 127.
Welsbach, Junior, light, 104.
Welsbach light, 101.
Wenham gas burner, 90.
Work-room illumination, 243.
Work-shop illumination, 247.

X.

X-ray reflectors, 205.

Y.

Yellow components in light, 32.

89080454069

B89080454069A